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BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK

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BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK

No. 38A December 1988

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EDITORIAL

In Bulletin No. 36 (Index Volume to Bulletin Nos. 1-35) we promised a consolidated reprint of Bulletin Nos. 1-18 which were issued in duplicated quarto or A4 format between 1953 and 1969. Here is the first of two volumes of reprints (No. 38A) containing original Bulletin Nos. 1-10.

The deteriorating quality of the original paper, and the relatively poor quality of the duplicating method of reproduction made facsimile reproduction impossible. The entire text has therefore been re-set and the figures re-drawn or re-copied, but without alteration. Please do not respond to out-of-date requests for subscriptions, or write to (former) members at out-of-date addresses! Because of the smaller A5 page size of the present format some of the original figures now appear somewhat over-reduced. If you would like a copy of any particular figure at the original quarto/A4 size please request one from the Editor.

B.M. Funnell
P.G. Cambridge

COVER PHOTOGRAPH (Paramoudra Club, 26 July 1950)

Back row (left to right): F.A. Haverson, J.S. Atkinson, B.M. Funnell, R.G. Thurrell, R. Dyer, V.F. Hunter, D.E.H. Reeder, B.R. Richmond, I.J. Harrowven, T. Chamberlain;

Front row (left to right): D.C. Croghan, A.P. Dady, A.J. Martin, W.A. Gordon, G.B. Todd.

PARAMOUDRA CLUB

Tel. 26154

88 Cecil Road
Norwich

13th April 1953

Dear Member,

As you may by now have heard it was decided at the meeting on Thursday 26th March that conditions were now favourable for the Club to begin to publish some sort of Bulletin or News-sheet to publicise its activities and to enable members who are often not able to attend meetings to keep in touch with local geology. The cost of this venture will be carried by the Club and copies of the News-sheet will be circulated to all subscribing members free of charge.

At first the publication will take an experimental form and it will probably consist of a single duplicated quarto sheet, issued three or four times a year and for convenience of filing used on one side only. The success of this experiment will depend largely upon the response of individual members, for they are the people who can supply the news. Information of any sort which has a bearing on local geology will be welcome. Reports of research and requests for information; notices of forthcoming papers of local interest, and, if possible, the source from which offprints may be obtained; records of important new or temporary exposures; and re-interpretations of old evidence are some of the topics which, it has been suggested, might be of interest. It will of course also be possible to publish the Club proceedings, notices of future meetings and membership lists.

Please send your news to the above address with as little delay as possible. Without it the News-sheet can hardly be expected to be a success.

Yours sincerely,

A Paget Baggs

(A. Paget Baggs)
Editor

No. 1

September 1953

Editor: A. Paget Baggs
Joint Secretaries: G.P. Larwood
A.J. Martin

As you will realise this Bulletin is of much greater length than was originally suggested. This is largely due to the high cost of postages and enevelopes relative to that of duplicating.

The enclosed list of members and addresses is as complete as we have been able to make it. Notification of any errors should be sent either to one of the Joint Secretaries or to me.

Mr. G.P. Larwood sends the following note which should be read in conjunction with his note on the Easton Bavents section:- (9th Aug. 1953) On the recent Paramoudra Club excursion to the Chillesford Beds type section an excavation was made, enabling members to examine sections first described by Prestwich and F.W. Harmer. The marked dissimilarity between the Easton Bavents deposits and the type section of the Chillesford Beds was noticeable. Members also examined various exposures of the Red Crag - including the type section of the Butleyan Stage of the Red Crag at Butley.

It seems that the Chalk Pit at Caistor has at last been closed to commercial working. On a recent visit we found the gates closed and the path partly overgrown with nettles. The face of the beds above the Chalk is now badly weathered and most of the lower part of the section is covered by talus.

Two papers of local interest have been published recently. The first is the 'Stutton Brickearth, Suffolk' by H.F.P. Spencer, F.G.S. (P.G.A., Vol. 64, Pt. 1, 1953, pp.25-28) and the other is Dr. J.M. Lambert's Presidential Address to the Norfolk Naturalists Society, entitled 'The Past, Present and Future of the Norfolk Broads' (T.N.N.N.S., Vol XVII, Pt. IV, pp.223-258 & 8 Plates). A copy of the former may be borrowed from me.

The Norfolk and Norwich Naturalists Society and the Club - During the early summer negotiations took place between the Committees of the Naturalists Society and the Club and as a result the Club has become a member of the Society. This entitles members of the Club to take part in the outings and to attend the indoor meetings of the Society. The Club will also receive one copy of the Transactions of the Society.

The Annual General Meeting has been provisionally arranged for the evening of Monday 21st December. The time and place will be fixed later.

A.P.B.

PARAMOUDRA CLUB

Constitution, 19th December 1951

(Amended 22nd Dec. 1952; Addition 2nd Jan. 1953)

1. The name of the Club shall be the 'PARAMOUDRA CLUB', hereinafter called the Club.

2. The mascot of the Club shall be a paramoudra.

3. The object of the Club shall be the promotion of geological learning and research - particularly that relevant to East Anglia.

4. Election of members:

Candidates shall be invited to stand for election as members of the Club. They may be proposed and seconded at any meeting - provided that five members are present.
The election is valid only if there be no objectors to the election of the proposed candidates.
A personal knowledge of the candidate is essential before consideration for membership.

5. The Club shall have its Head Quarters in Norwich and groups may be established with the sanction of a general meeting.

6. Club Officials:

(i) The Club shall have a President, Secretary, Treasurer and Reader. The Secretary shall take on the role of Vice-President.
(ii) Groups shall elect a Chairman and Secretary and any additional officials desired by them.

7. The Club committee shall consist of the Club President, Secretary and Treasurer, plus one representative from each group in existence at the time. The Reader shall be co-opted if the committee proves to consist of an even number of officials.

8. Election of officials:

Candidates shall be proposed and seconded at the Annual General Meeting and elected for a period of twelve months on a simple majority determined by secret ballot.
All officials are eligible for re-election.

9. There shall be no proxy vote.

10. All general meetings shall open with a reading fromthe works of Sir Charles Lyell which shall be followed by the presentation of the minutes of the previous meeting - except on field meetings when the minutes of the previous meeting shall be deferred until the beginning of the next indoor meeting.

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11. All members shall pay an annual subscription of two shillings and six pence to the Club. The subscription shall fall due on the first of Janaury each year. No member shall benefit from he privileges of the Club unless his subscription is up to date. Any member failing to pay his subscription for three consecutive years is excluded from membership.
Group subscriptions shall be decided by each group when found necessary..

12. An Annual General Business Meeting shall be held in December of each year, and other general meetings shall be held when possible.

13. The members of the Club reserve the right to offer annual honorary membership to those deemed fit; notably those overseas and those unable to benefit directly from the proceedings of the Club.

14. This constitution may not be amended or replaced except by a two-thirds majority of the members present at the Annual General Meeting.

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THE PARAMOUDRA CLUB 1953

President: R.G. Thurrell

Treasurer: A.P. Baggs

Joint Secretaries: G.P. Larwood, A.J. Martin

Norwich Group Representative: B.R. Brown

List of Members

A.C. Aitkens	Dept. of Engineering Geology, The University, Kingston, Ontario, Canada.
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P. Browne	46 Esdelle Street, Norwich & C.N.S.
N.B.G. Bush	36 Appleyard Crescent, Mile Cross, Norwich.
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W.A. Gordon	70 Springfield Rd., Gorleston, Norfolk & Dept. of Geol., University College, Gower St., London WC1.
A.E. Green	113 Gordon Avenue, Norwich.
I.J. Harrowven	11 Warwick Street, Norwich & Dept. of Geology, University College, Gower Street, London WC1.
B.M. Funnell	Beverley, Norwich Road, New Costessey, Norwich & Trinity College, Cambridge.
F. Haverson	5 The Crescent, Drayton, Norwich & Dept. of Geology, The University, Bristol 8.
D. Howlett	1 Bush Road, Upper Hellesden, Norwich & Castle Museum, Norwich.
V.F. Hunter	21 Boundary Lane, Thorpe, Norwich & Dept. of Geology, Kings College, Strand, London WC2.
A.C. Jermy	Tandem, East Avenue, Brundall, Norwich & Dept. of Botany, University College, Gower St., London WC1
G.P. Larwood, B.Sc., F.G.S.	376 Bowthorpe Road, Norwich & Dept. of Geology, British Museum (Nat.Hist), S. Kensington, SW7.
A.J. Martin	73 Brian Avenue, Norwich & Dept. of Geology, University College, Gower Street, London WC1.
B.R. Playle	44 Kimberley Street, Norwich & C.N.S.
A.W.R. Potter	3 Foulgers Opening, Norwich & C.N.S.
D.E.H. Reeder	Hillcott, Bunwell, Norfolk & Dept. of Chemistry, The University College, Hull.
A.F. Riches	Garden Cottages, Thickthorn Hall, Hethersett, Norwich & C.N.S.

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B.R. Richmond, B.Sc.	The Kennels, Ringland, Norwich.
A.G. Seaman	29 Junction Road, Norwich & Dept. of Geology, The University, Leeds.
B.D.T. Speechley	16 Alford Grove, Sprowston, Norwich & C.N.S.
P.J. Stibbard	82 Alexandra Road, Norwich & C.N.S.
J.V.H.G. Symonds	153 Earlham Green Lane, Norwich & C.N.S.
R.G. Thurrell, B.Sc.	The Firs, Hempnall, Norfolk & Dept. of Geology, Kings College, Strand, London WC2.
G.R. Tresise	227 Earlham Road, Norwich & Dept. of Geology Queen Mary College, Mile End Road, London E1.
J. Welsted	15 Osbert Close, Sandy Lane, Norwich & C.N.S.
A.G. Wright	29 Trinity Street, Norwich & Dept. of Geography, The University, Bristol 8.
D. Mickelburgh	29 Meadowbrook Close, Norwich.

Cliff Sections Between Caister and Scratby

In the course of the storm which hit the Norfolk coast in February last much of the unprotected cliff betweeen Caister and Scratby was eroded, exposing sections which had not been studied, while in a fresh condition, for many years.

The section is of interest on account of all three units present. At the base is a variation of the Norwich Brickearth, which is overlain by the only constant series along the whole section, i.e. the Corton Sands. This latter series varies in thickness and is typically fine- or false-bedded. Often there is a comminuted shell bed near the base and thin seams and pockets of broken shell and small pebbles occur throughout the series whilst at the top is a variable but finely laminated clay sequence.

The Great Eastern Boulder-Clay, coming in and overlying the Corton Sands north of California Gap and marked by much chalk and flint, thickens northwards. The Boulder-Clay consists of: a) to the South, the Chalky-Jurassic, and b) to the north, the Great Chalky Boulder-Clays. The lateral junction between these two occurs above 900′ south of Scratby (Beach Road) steps but the junction is however difficult to define owing to weathering and slumping.

A further point of interest is that the Brickearth below the Boulder-Clay junction zone is contorted and the Corton Sands (the overlying deposits) are contorted in with it. This zone of contortion dies out laterally to the north and south, away from the junctionof the Boulder-Clays. Futhermore the contortions die out upwards as well so that the Boulder-Clay/Corton Sands junction plane is only slightly disturbed and uneven.

Finally the nature of the Brickearth is of interest in that although it lacks rock erratics it contains many worn fragments of shell, including Macoma balthica. It is fairly coarse and unbedded, and occasional flint and quartzite pebbles are found towards Caister.

Thus briefly the points of interest of the section are:-

1. The basal Brickearth series which may be compared with the Norwich Brickearth of the type sections. Is the shell content derived from the Weybourne Crag?
2. Problems concerning the contortion and disturbance of the lower beds, which involve the mixing of waterlain deposits by contortion.
3. It has provided material for a re-determination of the junction between the Great-Chalky and the Chalky-Jurassic Boulder-Clays.
4. The good exposure of the Corton Sands makes possible a detailed study of their fauna.

Mrs. Charles Green of Caister has made very detailed records of the section at all points and Mr. G.P. Larwood and myself have observed the exposures. It is hoped to publish a full account of these observations in the forthcoming Transactions of the Norfolk and Norwich Naturalists Society.

A.J. Martin

(No.1)

Easton Bavents Cliff Sections - Southwold, Suffolk

The variably exposed cliff sections were examined from Southend Warren - north of Southwold - to Easton Bavents Broad. This examination showed that the threefold division, established by Whitaker in the G.S. Memoir 'The Geology of Southwold and the Suffolk Coast', is still apparent. A series of sands and gravels overlies a blue-grey clay above sands with shells and shell beds.

No fauna was found in the upper two units, but beneath the clay the sands contain intermittent shells and well developed shell beds of a Norwich Crag aspect. An important problem arises from the concept of the Chillesford Beds as the deposits of an estuary of the proto-Rhine flowing from a landmass lying to the south. In the type section at Chillesford frequent minute mica flakes occur in the clayey series, and it has been suggested that this mica derives from the ancient Ardennes Massif. There is no evidence of mica concentration in the clay at Easton Bavents - it may well be that the clay is, in fact, an essentially marine deposit, though there is at present at Easton Bavents no fauna to check this.

Prestwich recorded a separate faunal list of marine forms from which he termed the 'Chillesford Clay' of Easton Bavents. The Rev. O. Fisher also recorded a marine fauna from sand lenticles included in the clay. The presence of such a marine fauna is not consistent with a strictly estuarine environment of deposition, and J.D. Solomon's more recent heavy mineral analysis (1935) revealed a suite of minerals all of Scandanavian origin. F.W. Harmer (1896, 1902, 1909) first suggested estuarine conditions of deposition for the Chillesford Clay and subsequently elaborated this theory when referring to the type section.

Throughout the references to the Chillesford beds it is apparent that some confusion arose as to their vertical limits and their origin. In a paper, which it is hoped, will be published in the 1954 Transactions of the Suffolk Naturalists Society, the detailed lithology of the sections is described and the stratigraphic problems are discussed and - in the light of recent work - some attempt is made to resolve the conflicting views previously expressed. It is suggested that a more appropriate nomenclature for the threefold sequence exposed at Easton Bavents is as follows:-

3. Pebbly Series - waterlain sands and gravels
2. Chillesford Clay - largely an open water deposit
1. Norwich Crag - shallow water shelly facies.

A description of the Norwich Crag of Easton Bavents is also included and a composite faunal list appended. The extensive fauna listed represents the results of recent collecting and the material preserved in the Searles Wood, Norton and Crowfoot Collections and the published faunal lists of Prestwich and Clememnt Reid. Additions to the record for the Easton Bavents Norwich Crag - made during recent collecting - include: _Ostrea_ sp., _Spisula elliptica_ (Brown), _Chlamys tigerina_ (Müller), _Glycimeris glycimeris_ (Linne), and mammalian fragments including: molar of _Hippopotamus_ sp., premolar of _Equus_ sp. (stenonis group), teeth, skull fragments and limb fragments of _Elephas_ sp. and of _Cervus_ sp. Some attempt has been made to interpret the palaeo-ecology of the deposit.

G.P. Larwood and A.J. Martin

(No.1)

Recent Work on the Constitution of the Chalk

At a recent meeting of the Geological Society of London Mr. Maurice Black, M.A., F.G.S. delivered a lecture on the constitution of the Chalk.

The lecturer referred to earlier researches which showed that the Chalk of England and France was composed almost entirely of organic material, and to more recent work which suggested that much of the chalk matrix was precipitated chemically from sea water. This theory was based on a comparison with shoal water precipitated oozes of Florida and the Bahamas.

Detailed examination of the finer fractions of Chalk - made by Mr. Black, using an electron microscope - gave little support to the precipitation theory. Ordinary white Chalk was a mixture of coarser Molluscan debris and Foraminifera embedded in a finer matrix of coccoliths and their disintegration products. Mechanical analysis of Chalk revealed a complex size distribution of component particles and this distribution varied considerably from one horizon to another. All analyses had certain peculiarities in common, and there were clearly defined limits to the way in which size distribution could vary. Within the normal grain size limits in typical soft chalks - not coarser than 100 microns nor finer than one half micron - the properties of the main constituents could vary considerably to give chalk with different bulk properties. Dominance of _Inoceramus_ prisms, or other shell debris, gave a slightly gritty texture but friable rock; chalks with abundant Foraminifers or spheres were apt to be hard or nodular. Preponderance of coccolith material gave the common soft chalks - as in the _Micraster_ zones.

'The finest fractions of the Chalk contained innumerable bodies resembling the coccoliths produced by certain living planktonic algae and found abundantly in modern pelagic deposits. Perfect specimens were present in large numbers, and all stages of disintegration could be seen down to the individual component crystals'. The finest chalk particles were - significantly - of the same order of size as the individual crystals of the associated coccoliths.

' The calcite of typical soft chalk thus appeared to be provided entirely from organic skeletons, the coarser fractions coming from the shells of invertebrates, the finer from planktonic algae'. In contrast modern precipitated oozes contain little shell material, 'and their finer fraction has a great abundance of minute aragonite crystals, but hardly a trace of coccoliths'.

The above account of an important contribution to Cretaceous geology is taken from a precis published in the Proc. Geol. Soc. of London No. 1499, 29th May 1953, which also includes discussion contribution on Mr. Black's lecture.

G.P. Larwood

(No.1)

PARAMOUDRA CLUB BULLETIN

No. 2, April 1954 Editor: A. Paget Baggs

It is with profound regret that we have to record the death of G.B. Todd in Aden hospital on Thursday, March 11th, 1954. Gilbert Todd was educated at the City of Norwich School and at King's College, University of London, where he graduated with honours in Petrology in June 1953. From September 1953 until his death he was employed with a Geological Surveying team in the hinterland of Aden. He had been one of the Founder Members of the Club and his last field excursion was that to Chillesford and Bawdsey in August.

R.G.T.

Field Trip. B.M. Funnell will lead a Club Field Trip in the Costessey area on Tuesday, April 13th. The principal exposure to be visited are those listed in his notes in this Bulletin. Meet at Costessey Oval (with own transport) at 9.0 a.m.

Lecture. Hallam Ashley, F.R.P.S. will talk to a meeting of the Club on Monday, April 26th, at 7.0 p.m. in the Lecture Room of the Castle Museum. The subject of his talk, which will be illustrated, is 'The Geology and Scenery of Northern Ireland and Some Comparisons with the Geology of East Anglia'.

The following have been elected to Membership since the publication of the 1953 list:-

C.E. Ransom	52, Spixworth Road, Old Catton, Norwich & C.N.S.
D.A. Guymer	11, Heartsease Lane, Sprowston, Norwich & C.N.S.
J. Tessiter	17, Meadowbrook Close, Norwich & C.N.S.
C.A. Sizer	Dept. of Geol., University College, Gower St., London WC1
H. Robinson	5 Abbey Court, Bracondale, Norwich
W. Utting	93, Carrow Road, Norwich & C.N.S.
P.H. Banham	132, Thunder Lane, Thorpe, Norwich & C.N.S.

The Club has also agreed to exchange publications with the Suffolk Naturalists Society.

Members may be interested to know that the Norwich Central Public Library has recently purchased a complete set of the Proceedings of the Geologists Association and these are now available for reference.

The Committee for 1954 is:- President, R.G. Thurrell; Secretary, G.P. Larwood, Treasurer, A.J. Martin, Reader, P. Browne.

At the Annual General Meeting it was unanimously decided that the 1954 subscription for Ordinary members should be five shillings. The Treasurer would be pleased to receive this from those who have not already paid.

A.P.B.

(No.2)

1. An Abstract of Information Obtained from Borings in Norwich, 1951

The local stratigraphy between Grapes Hill and Bracondale, Trowse and Whitlingham Sewage Farm.

The surface of the Chalk has an apparent dip of 1 in 720 E (from 60′ O.D. to 30′ O.D.), and normally varies less than 3′ from a plane along the line of the borings.

The Norwich Crag Series (taken here to include everything between the Chalk and the Norwich Brickearth) shows considerable lateral and vertical variation. The variation is confusing and the following is an inadequate attempt to produce a few working generalisations:

(i) A macroscopic fauna occurred only E. of the Yare within the bottom 10′ (i.e. below 55′ O.D.)
(ii) Sand, relatively free from clay and gravel, occurs only at levels between 10′ and 20′ above the base E. of the Yare
(iii) Clay bands which may or may not be yellow brown and micaceous*, are found at all levels, but more frequently in the E. half of the Whitlingham section, and not at all in association with gravels containing quartz pebbles of 2-4 cm diameter
(iv) Rounded quartz pebbles (1-1.5 cm diam) are present throughout the series W. of the Yare, but only in the top 20′ E. of it (i.e. usually above 55′ O.D.)
(v) Larger rounded quartz pebbles (2-4 cm diam) comprising up to 50% of the phenoclast component (always less than 25% E. of the Yare) occur at levels about 65′-70′ O.D. The associated flints are subangular to subrounded whereas at lower levels they are subrounded to rounded. There is also a tendency for the interstitial sand to be replaced by a quartz grit in the higher levels.
(vi) The characteristic basement flints were not recognised W. of the Yare
(vii) Characteristically the series consists of a rounded to subrounded flint gravel (2-4 cm diam) with interstitial sand.

The Norwich Brickearth rests on the N.C.S. at about 85′ O.D. W. of the Yare; it is not present to the E. It is succeeded by Sand and Gravel at 100′ O.D. The brickearth is a stiff chocolate brown clay.

The Sand and Gravel provides insufficient samples for general description bu the flint is usually angular.

The Chalky Boulder Clay E. of the Yare rests on an undulose surface of the N.C.S., and, being both decalcified and oxidised, is virtually indistinguishable in the hand specimen fromthe Norwich Brickearth. It is overlain and overlapped by a loamy light brown sand which probably results from further weathering.

*mica is not always seen in hand specimens but is only obvious after a mechanical separation when it forms a large proportion of the bulky (50%) silt fraction.

2. The Yare Valley Buried Channel

A channel revealed in the Yare Valley at Trowse is cut into Chalk to over 71.5′ below O.D. and is probably about 250 yards across. No clear indication of the transverse profile can be obtained, and even

(No.2)

the postulation of a channel is based on a comparison with better proved examples in East Anglia and the slender evidence of Valley Boulder Clay occurrences at Cringleford and Thorpe.

The channel is filled on the E. side, from the bottom upwards, by:
(i) Blowing sand and gravel of 1-4 cm diameter flint, quartzite and hard chalk phenoclasts - the flint freshly fractured but some smaller pebbles rounded. The whole is covered in a chalk flour and there are fresh fragments of Chalk fossils and grey flint.
(ii) Gravel - this contains some white and grey quartz pebbles but most phenoclasts are flints. These are either fresh retaining their cortex (fractured when greater than 4 cm diam, but sometimes entire when less) or subangular to rounded. Normally there is no interstitial sand but there may be some grey sand with chalk and flint chips. Other gravels occur at higher levels on the sides.
(iii) Grey Sand with a considerable amount of chalk and flint chips.
(iv) Blue Boulder Clay about 50′ thick. A gravel at the base of the angular (2-4 cm) flint and rounded (1-1.5 cm) quartz may be almost free from clay. The boulder clay becomes less stony and more chalky towards the top. There is some chalk-cum-clay. The topmost two or three feet are a mottled brown-grey colour.

The W. side is filled by gravels, and also sands and clays, which are predominantly brown in colour, in contrast with tbe blue or grey of the E. side. They could all be derived from the deposits overlying the chalk of Bracondale Hill. Only the lowest gravels bear any resemblance to those on the E. and these are similar to those mentioned as 'others' under (ii).

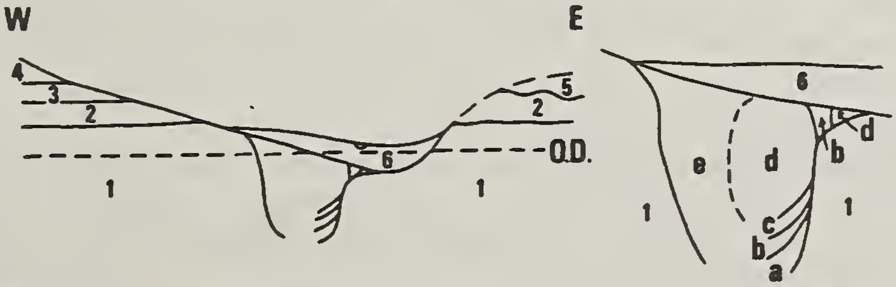
The whole is overlain by river gravel, similar to that in the Wensum Valley, which reaches a maximum thickness of 20 to -10′ under the present Yare on the E. margin of the buried channel.

No buried channel was revealed in the Wensum Valley where borings straddled the valley near Norwich City Station and the maximum depth of river gravel was -17′ O.D.

Comment

The data obtained concerning the local stratigraphy, especially with regard to the N.C.S., fully justify the cautious approach maintained by H.B. Woodward in 'The Geology of the Country around Norwich' (1881). The distinctive quartz-bearing layers may be separable as a unit akin to the Westleton Beds.

P.G.H. Boswell dealt adequately with the problem of buried channels (Q.G.J.S. vol. LXIX 1913) and although some 200 borings have now penetrated some 10 channel systems in E. Anglia there seem to be no further publications on the theoretical aspects.



a. Blowing sand and gravel
b. Gravel
c. Grey Sand
d. Boulder Clay
e. Bracondale Gravel etc

1. Chalk; 2. N.C.S; 3. Norwich Brickearth; 4. Sand and Gravel; 5. 5. Chalky Boulder Clay; 6. River Gravel (Vertical exaggeration x12)

B.M. Funnell

(No.2)

Notes on some exposures in Glacial Beds west of Norwich (1954)

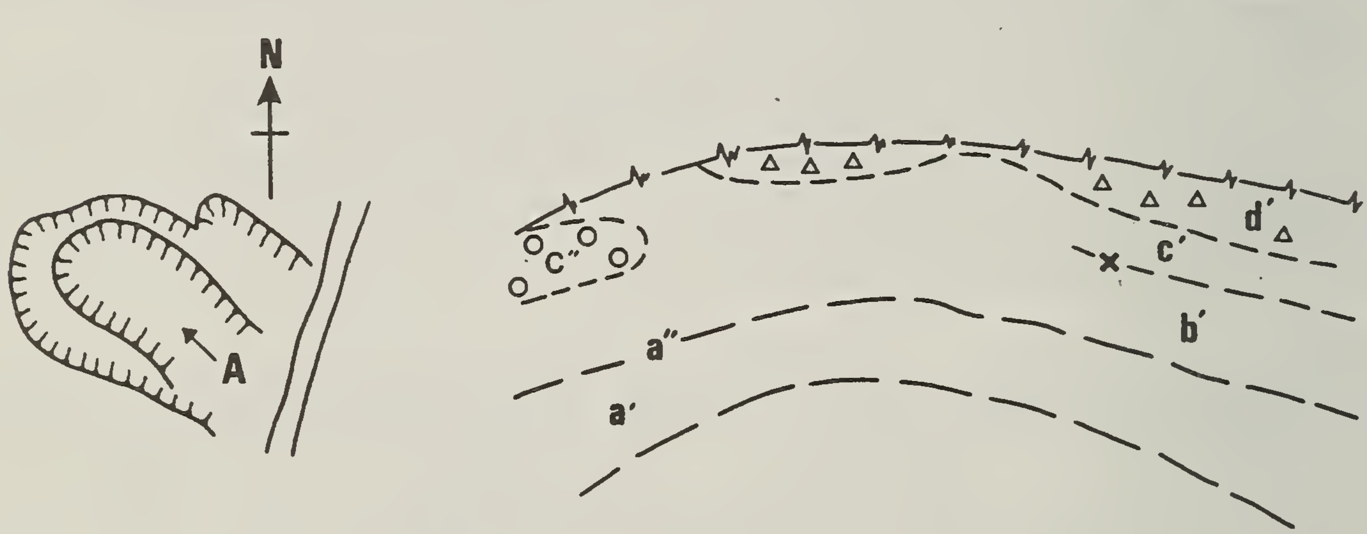
Geological Survey Classification:

J.H. Blake 1884	H.B. Woodward 1881
Plateau Gravel	Gravel and Sand
Boulder Clay	Boulder Clay
Sand and Gravel	Sand and Gravel
Loam and Marl	Brickearth, Stony Loam and Sand

1. Easton G.R. 63/148108 approx. Sandhill Quarries and Thorpe Gravel Co. Surface about 155′ O.D.
   About 15′ of coarse gravel, rough horizontal bedding, lenses of sand or grit up to 5′ thick filling shallow channels, often with a loamy base.
   Boulder Clay (?) near road just below surface in Thorpe Gravel Co. Pit. Uppermost layers often with vertical flints or otherwise contorted (stratification).

2. Marlingford G.R. 63/121093 Surface about 150′ O.D.
   Flint Gravel in loam, lying in hollows in flint gravel in sand similar to that at Easton. Exposed to about 20′.

3. Hockering G.R. 63/088128 Surface about 150′ O.D.



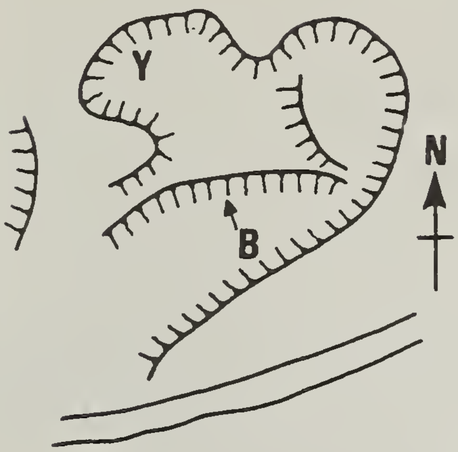
Panoramic Section from A

a′ buff sand, base not seen, with 'drapery' iron staining.
a" sand with abundant chalk grains, considerable smut and sometimes finely bedded.
b′ pale buff sand, with many flints and chalk pebbles, 1"-2" diameter, and clayey bands.
c′ buff sand alternating with gravel layers, iron pan at x.
c" large flint gravel, subangular and rounded, usually 3"-6" diameter, with many erratics, overlain by brown and yellow sands with strings of flints.
d′ brown sandy loam containing grey and black, rounded and battered - some cortex retaining, sporadic erratics, all crudely layered.

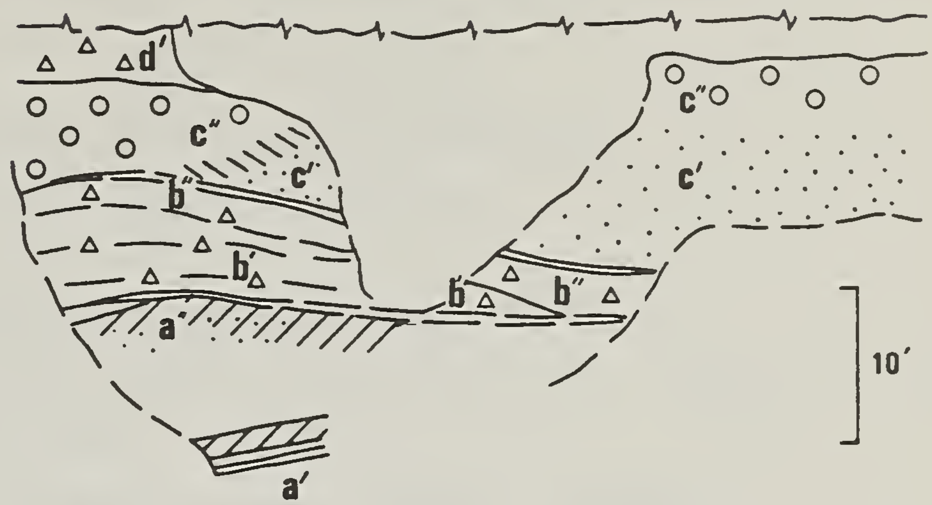
(No.2)

4. Honingham G.R. 63/093124 Surface probably just above 150′ O.D.

Plan



General view from B



a′ light buff sand with chalk grains, finely bedded or current bedded.
a" buff sand with bands and specks of smut, the junction with b′ is smooth and at a small angle to lines of iron staining.
b′ grey clay with angular flints and chalk pebbles in abundance; to the left there are sandy intercalations and little or no chalk. Some erratics.
b" loamy brown sand, with stones as b′ but no chalk. Some erratics.
c′ buff sand, ‘undulose’, iron staining, smut and chalk grains near top.
c" buff sand with horizontal strings of flints, ½"-2" diameter.
d′ layered brown loamy deposit at base. In upper part sandy and becoming pale, containing large little worn, cortex retaining flints (some tabular). At Y there are patches about 3′ by 2′ of chalk rubble.

5. Old Costessey G.R. 63/155120 approx. Norwich and District Gravel Co. Surface about 155′ O.D.
Coarse gravel of ‘Plateau’ type, i.e. as at Easton, 15′-20′ passing down via badly exposed intermediate beds into:-
Extensively false-bedded and fine-bedded buff sands with chalk grains and smut, seen to 20′ plus.

6. Costessey Brickyard at less than 100′ O.D.
About 12′ of pinky-brown clay containing flints and chalk, rough layers inclined at about 10′ west.
Overlain by white chalky band, sand, and sand and shingle.

N.B. These notes are intended as a guide to further observations; they are not exhaustive and absolute accuracy cannot be guaranteed.

For reference purposes only:
Exposures 1, 2, 3, 4, are within an area mapped as plateau gravel.
Exposure 5 in an area mapped as sand and gravel.
Exposure 6 in an area mapped as boulder clay.

B.M. Funnell

(No.2)

(No.2)

PARAMOUDRA CLUB BULLETIN

No. 3, August, 1955 Editor: G.P. Larwood

EXCURSION TO RUNTON - SEPTEMBER 5th 1955

Change in time of departure

THE BUS LEAVES NORWICH BUS STATION AT

8.35 A.M. MEET AT 8.30 A.M.

SUBSCRIPTIONS FOR 1955

Members are reminded that these become due on January 1st. Subscriptions should be sent to:

V.F. Hunter, 21 Boundary Lane, Thorpe, Norwich.

SURVEY OF THE R. TAS VALLEY
(PROGRESS REPORT)

A survey was made (1) to investigate the possible existence of river terraces, (2) to determine their geological history, and (3) to study the geological history of the river valley and the adjacent terrain.

Levelling of the thalweg was begun; three cross-valley sections are being prepared, and topographic mapping of the terrace features is completed.

<u>Thalweg</u>. An attempt to produce a thalweg was unsuccessful due to inadequate levelling equipment. However, no knick-points appear to be present.

<u>Terrace features</u>. All the terrace features have prominent front edges, particularly well preserved in the Caistor St. Edmunds area, but the back-edges are sometimes obscured by downwash from the valley slopes. The height of the terrace features varies between 50′ and 30′ above O.D. from the source of the river to its confluence with the R. Yare.

<u>Pleistocene Stratigraphy of the river valley</u>.

All three cross-valley sections revealed (1) evidence of a buried channel cut into the underlying chalk, (2) a flat erosion surface on the chalk, (3) blue-grey chalky boulder-clay at two or three levels, (4) sands or mixed sands and gravels apparently separating the boulder-clays, and (5) two alluvial deposits of different ages.

I. THE CAISTER SECTION
- (e) Sands, sands and gravels
- (d) Chalky Boulder-clay
- (c) ?Mid-glacial pebbly sands or ? associated Norwich Crag
- (b) Norwich Crag
- (a) Chalk

(No.3)

Remarks: The presence of a buried channel is inferred from the evidence of the section and a deep boring at Caistor Old Hall Farm where the chalk was penetrated at a depth of -52′ O.D. The cutting of the channel predates the boulder-clays and alluvial deposits, but its exact age is as yet unknown.

The erosion surface on the chalk, at about 40′ to 50′ above O.D. in this area, has an easterly dip of approximately 1 in 500.

Norwich Crag is identified by faunal remains, but although Woodward recorded an outcrop at Stoke Holy Cross, the deposit is not now recognisable west of the R. Tas nor further upstream. Laminated micaceous sands and a pebbly series are associated with the Crag and are apparently inseparable from it. These deposits have also been called "Middle Glacial": at present there is no definite proof for either view. It has been suggested that the Crag deposits of this area may have been glacially transported, but their generally undisturbed condition and the absence of a glacial matrix make such an origin unlikely.

Blue-grey chalky boulder-clay occurs at three levels, the middle deposit containing a large proportion of Jurassic erratics. The boulder-clay exposed in Caistor pit appears to have compressed part of the underlying micaceous sands. This feature, which is difficult to relate to any particular event, presents a special problem when correlation of the middle and upper boulder-clays is attempted.

The sands and mixed sands and gravels, apparently overlying both middle and upper boulder-clays, are of uncertain age. These deposits vary considerably; on the east side of the valley they are very fine sands, while on the west side they are composed mainly of coarse flint gravels.

The sequence of events seems to have been: (1) infilling of the original valley to an unknown level with glacial drift; (2) cutting of a channel in the drift; (3) infilling of this new channel with alluvium to about 30′ to 40′ above O.D; (4) rejuvenation and formation of terraces in the alluvium of stage 3; (5) infilling of the valley cut during stage 4 with newer alluvium to about 20′ above O.D; (6) present day slow downcutting.

II THE STOKE HOLY CROSS SECTION

Certain features, which were not encountered at Caistor, are present in this area: (a) erosion features in the chalk, and (b) a pebble bed at 65′ above O.D.

Remarks: The buried channel is indicated, but the evidence is less conclusive than in the Caistor area for there is no deep boring. Norwich Crag was not recognised in this section. A blue-grey boulder-clay, containing much chalk, appears at two levels, infilling the channel and forming high ground above the chalk. The two deposits are almost identical, and are apparently of the same age.

(No.3)

In this section, sands and gravels do not occur on the east side of the valley, but a pebbly series outcrops on a spur a few hundred yards south of the line of section. This pebbly series is believed to overlie the boulder-clay with a similar relationship to the clay as the other sand and gravel deposits. On the west side of the valley, sands with angular flint form a relatively thick deposit.

Dunston Common is a well developed terrace feature, but its deposits, having a higher iron content and containing a large amount of angular and sub-angular flint, differ from those of other terrace remnants. The terrace is at about the same height as a niche cut in the chalk to the east of the river, but the correlation of these two features is not proved. There are also differences in level between the terraces on either side of the river at this point and between here and Caistor. Further work is needed before a sequence of events may be suggested.

III THE SHOTESHAM MILL SECTION

The work on this section is incomplete and as yet inconclusive.

Remarks: The chalky boulder-clay has a similar problematical relationship to the sands and gravels as in the other sections.

The sands overlying the boulder-clay to the west of the R. Tas have a similar appearance to those to the east, and it is probable, therefore, that the former also overlie the boulder-clay.

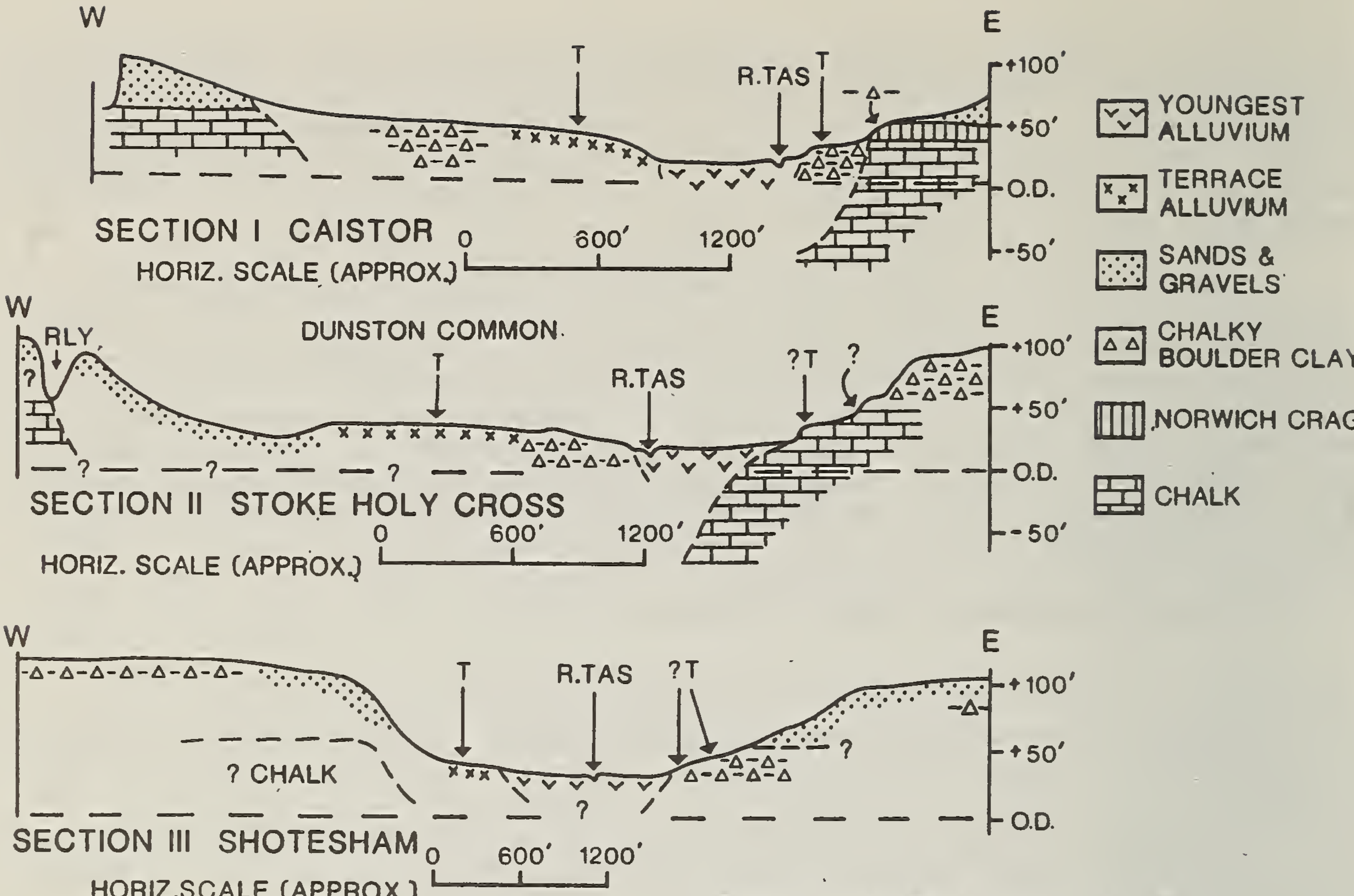
A buried channel is inferred from negative evidence: for chalky boulder-clay occurs in the valley bottom, and there is a considerable depth of alluvium, indicating the cutting of the present valley in deposits filling an older channel.

The terrace features, as may be expected about six miles from the confluence of the river with the R. Yare, are less distinct and their front edges are sometimes difficult to distinguish.

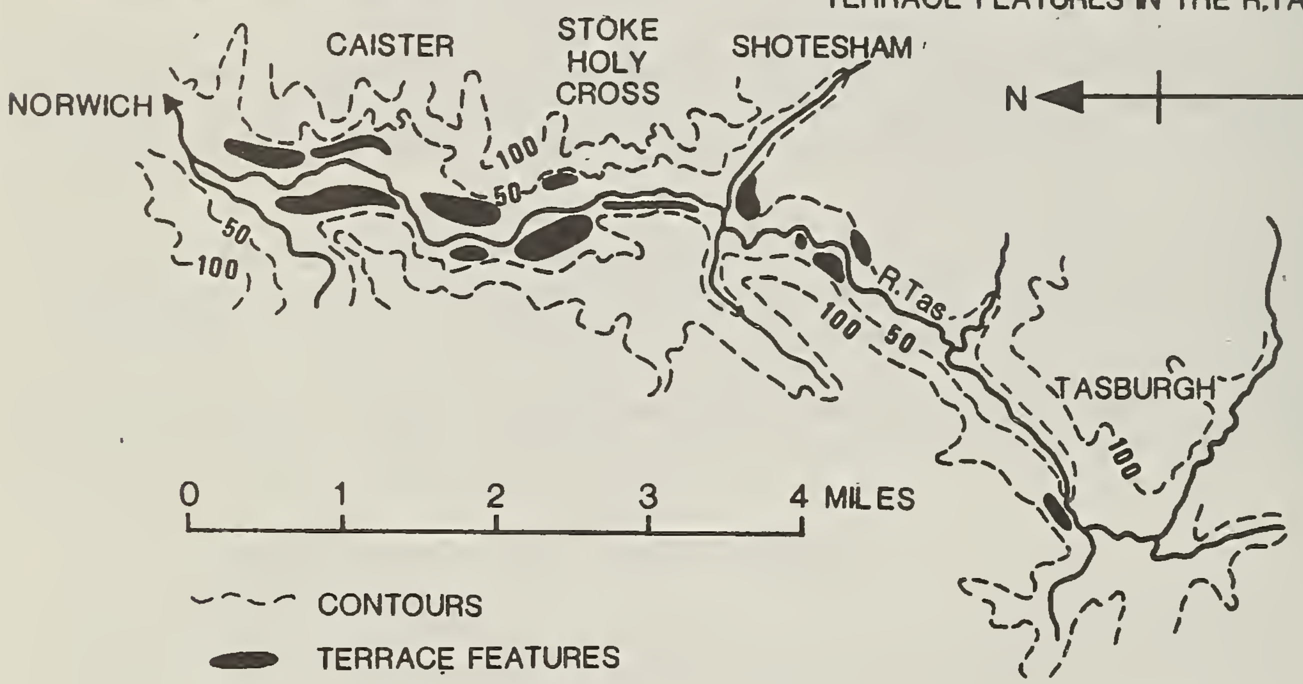
This section may prove one of the most useful on further investigation.

B.R. Brown
(December, 1954)

(No.3)



TERRACE FEATURES IN THE R.TAS VALLEY



(No.3)

THE AGE AND FAUNA OF THE Ostrea lunata CHALK AT MUNDESLEY, NORFOLK - EXPOSED 1898 & 1954

A recent temporary exposure of chalk with Ostrea lunata Nilss., on the foreshore at Mundesley, has given an opportunity to collect a wide varied micro- and macro-fauna which confirms the suggested Maastrichtian age of the beds (see Jeletsky, 1951).

An exposure of O. lunata chalk at Mundesley was seen by Brydone in 1898 and described briefly by him (1900, p.2). The recent exposure (1954) revealed a mass of very fossiliferous chalk of almost exactly the same size as when Brydone measured it. The chalk formed a low reef, just above the low-tide mark, about 25′ long and 6′ wide, running diagonally seawards about 100 yds. south of the cliff-steps leading down form the Kiln Camping Site at Mundesley.

The exposed chalk was soft and grey, with scattered, often broken, black flint nodules. Crushed shell fragments, particularly of O. lunata, were very common, producing a gritty appearance. The generally crushed nature of the chalk suggests that it has been glacially disturbed and compressed.

The following fauna was collected:- FORAMINIFERA - Bolivina spp.* (cf. incrassata, "gigantea", and decussens), plus long-range and some arenaceous foraminifera. PORIFERA - Porosphaera globularis and others. POLYZOA - Castanopora magnifica*, Membranipora spp., Vincularia spp., Onychocella spp., Pyripora cruciata and cyclostomatous forms. CEPHALOPODA - Belemnella lanceolata*, ?Nautilus spp. LAMELLIBRANCHIATA - Ostrea lunata*, O. vesicularis, Lima sp. ECHINODERMATA - Cardiaster ananchytis, Cyphosoma sp., Echinocorys scutata, Cidaris sp., Phymosoma sp., Pentacrinus spp., Bourgueticrinus sp., Metopaster sp. and other asteroid plates. BRACHIOPODA - Rhynchonella limbata, Magas pumilis, Carneithyris carnea, Terebratulina cf. gracilis. (Serpulids, one unidentified coral and fragments of fish vertebrae also found).

The forms marked with an asterisk (*) are typically Maastrichtian. The foraminifera content, in particular, is quite unlike any from the zones below, the species are characteristic of the Maastrichtian chalk of Hemmoor and Lüneburg, Germany.

D.R. HOWLETT & G.P. LARWOOD
(August, 1955)

REFS:

Brydone, R.M. 1900. "The Stratigraphy and Fauna of the Trimmingham Chalk", Dulau, London.

Jeletzky, J.A. 1951. "The Place of the Trimmingham & Norwich Chalk in the Campanian-Maestrichtian Succession. Geol. Mag., vol.88, no.3, pp.197-208.

(No.3)

PARAMOUDRA CLUB 1955

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contd. overleaf/

(No.3)

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ANY ERRORS OR OMISSIONS SHOULD BE NOTIFIED TO THE HONORARY SECRETARY

(No.3)

(No.3)

PARAMOUDRA CLUB BULLETIN

No.4. December, 1955 Editor: G.P. Larwood

ANNUAL GENERAL MEETING 1955

This took place at the Assembly House, Norwich, at 7.0 p.m. on December 21st 1955. The President addressed the Club on "The Evolution of the Southern North Sea Basin". The following were elected Officers to the Club for 1956:-

President - Mr. B.M. Funnell (re-elected)
Hon. Sec. - Mr. B.R. Brown (re-elected)
Hon.Treas.- Mr. P.H. Banham
Reader - Mr. D. Chapallaz
Editor - Mr. G.P. Larwood (re-elected)

Statement of Accounts for the year 1955 was circulated at the meeting.

SUBSCRIPTIONS

Members in arrears with their subscriptions are asked to send these to the Hon. Treasurer. Members generally are reminded that subscriptions for 1956 become due on Jan. 1st 1956. All subscriptions should be sent to the Hon. Treasurer, Mr. P.H. Banham, 132 Thunder Lane, Thorpe, Norwich.

A STUDY OF THE CLIFF SECTION AT EASTON BAVENTS, NEAR SOUTHWOLD, SUFFOLK

The section described extends from Southend Warren to Northend Warren. The succession, from the bottom upwards, consists of Norwich Crag, Chillesford Clay, Pebbly Series and "Loam". Almost everywhere the topsoil has an associated iron-pan.

The NORWICH CRAG (i.e. all visible deposits below the Chillesford Clay) consists of (a) Crag proper, (b) Sand. There are three varieties of Crag proper:-

(i) contains a great variety of fragmentary fossils along with limonite nodules, pebbles and sand; (ii) contains scattered lamellibranchs in a yellow-orange sand; (iii) consists of sand with or without gravel partings.

The CHILLESFORD CLAY is very variable, with sandy protions and even gravel in some sandy partings. The base is undulatory and possibly erosive and is followed by (i) alternating orange-brown clay and sand bands (usually the bands are up to 4" thick), (ii) grey clay, (iii) unbanded, red-brown, sandy clay.

The PEBBLY SERIES consists of pebbly gravels and sands, usually current-bedded, but sometimes normally bedded. There are two varieties:-

(i) orange and red sandy gravel. In the south the gravel is absent from the upper part. (ii) Leached sand. The finer material is iron-stained and a thin band of ferruginous sandstone occurs at the base.

The "LOAM" occurs in unstratified lenses and consists of pebbles in a clayey matrix. It is possibly a till.

An interesting structural feature is a "step" in the surface of the Chillesford Clay. This may represent a fault or a cliff, but the latter suggestion is preferred.

A series of mechanical analyses gave the following results for the sand-grade (particles greater than 3.00 mm being ignored).

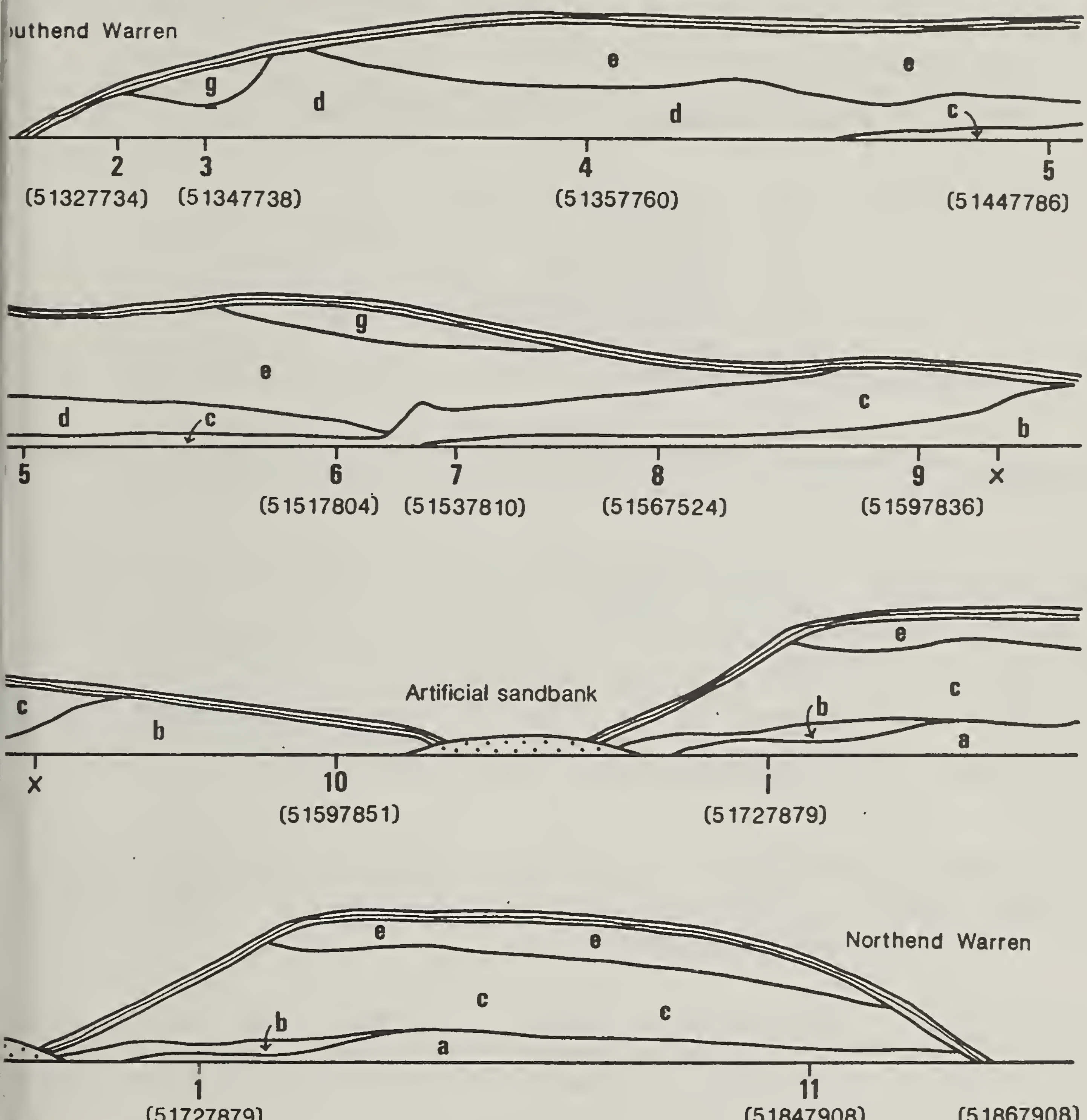
<u>Norwich Crag : Crag proper</u> (2 samples only), medians - 0.170 mm and 0.232 mm, sorting coefficients - 1.34 and 1.62, i.e. apparently slightly coarser and less well sorted in the north. The material from the south is bimodal and that from the north tends to be.

<u>Sand</u> (5 samples), medians - 0.175 mm to 0.209 mm, sorting coefficients - 1.14 to 1.63. Apparently less well sorted to the north and upwards in the succession, and coarser upwards in the succession.

<u>Pebbly Series : Orange-red Sandy Gravel</u> (4 samples), medians - 0.231 mm to 0.245 mm, sorting coefficients - 1.12 to 1.21. There is little variation in either size or sorting. There is possibly a tendency for material to be fine towards the top.

<u>Leached Sand</u> (5 samples), medians - 0.232 mm to 0.237 mm (with one exceptional value of 0.164 mm from the north), sorting coefficients - 1.15 to 1.29 (with 1.12 for the exceptional value). Apart from the exceptional value there is little variation in size, but there is, apparently, a tendency to better sorting northwards. Northward dipping foreset beds indicate a northward movement of material. There is possibly a tendency for the material to be coarser at the top and bottom. On the whole the Pebbly Series seems to be better sorted, and rather coarser than, the Norwich Crag. General tendencies seem to operate in different geographical directions.

(No.4).



Key:- SCALE : vertical 1" : 30′, horizontal 1" : about 300′

a = Crag; b = Sand; c = Chillesford Clay; d = Orange-red Sandy Gravel
e = Leached Sand; g = "Loam"; ═ = Topsoil

(No.4)

N.B. The samples taken were channel samples; most proved to be bimodal; the elimination of the fraction greater than 0.300 mm largely removed the coarser mode, leaving essentially unimodal distributions from which the above figures were taken.

[Abstract by B.M.F., approved by D.E.H.R]

D.E.H. Reeder (November, 1955)

REPORT ON THE EXCURSION TO RUNTON, SEPTEMBER, 1955

General Succession:-

7. 'Contorted Drift'
6. Sands (? = Corton Sands)
5. Cromer Till
4. ?Leda myalis Beds
3. Cromer Forest Bed Series
2. Weybourne Crag
1. Chalk

1. The Chalk was exposed on the foreshore from Sheringham to Cromer, but was not examined.

2. Weybourne Crag. At Sheringham its base is marked by an angular chalk breccia which grades rapidly upwards into a large flint conglomerate also containing mudstone nodules and occasional igneous and other erratic material. This is succeeded by a coarse sand. At Cromer, minor lateral changes are noticeable: the chalk breccia is absent, there is an increase in the number of mudstone boulders (these are about 3-5" in length), *Mya arenaria* and broken shells of *Cyprina islandica* appear. *C. islandica* also occurs at Sheringham.

3. Cromer Forest Bed Series. A poorly exposed series of variable sands, pebbly sands, pebble beds, with clays, silts and lignite layers. The Upper Freshwater Bed was locally exposed. A clay-pebble conglomerate also occurred locally.

5. Cromer Till. Pebbles and boulders of Chalk in the Till may be irregularly distributed or concentrated in distinct bands possibly indicating bedding. Folding of these bands may have been produced by ice contortion or by depositional factors.

6. Sands. These occur in depressions in the surface of the Cromer Till. The sands are bedded, and contain shell and lignite fragments. Steep dips are developed at the margins of the sand masses - they may be either pro-glacial or inter-glacial.

(No.4)

7. '<u>Contorted Drift</u>'. The boundary between the Cromer Till and the Contorted Drift is often obscured by large chalk erratics. Near Cromer a wedge of Chalk over 100 yards long occurs above the Cromer Till. The Contorted Drift itself contains large amounts of Chalk, either as large, variably orientated wedges or as boulders and bands of finer fragments.

An unusual erratic, probably belonging to the Cromer Till, was seen north of Beeston Church. A 'raft' of Chalk with its overlying Weybourne Crag rests on part of the Cromer Forest Bed Series and on Cromer Till.

B.R. Brown (December, 1955)

IF POSSIBLE MATERIAL FOR PUBLICATION IN THE BULLETIN SHOULD BE TYPED. IF IN MANUSCRIPT IT SHOULD BE LEGIBLE.

ALL MATERIAL FOR PUBLICATION SHOULD BE SENT TO THE EDITOR 317D, UPPER RICHMOND ROAD, PUTNEY, S.W.15.

(No.4)

PARAMOUDRA CLUB BULLETIN

No. 5. May, 1956. Editor: G.P. Larwood

THE EVOLUTION OF THE SOUTHERN NORTH SEA BASIN

A summary of the Presidential Address delivered to the

Paramoudra Club, December 21st, 1955,

by B.M. Funnell, B.A.

The STRUCTURAL LIMITS OF THE BASIN generally are set: (i) on the south by (a) the East Anglian - Brabant massif (upstanding from U. Carboniferous to L. Cretaceous), (b) the Weald - Artois axis (instituted Eocene, mainly Oligocene to Miocene); (ii) on the east by (a) the Erklenz [a_3] axis (uplifted Trias), (b) the Rhine shield (with Tertiary graben); and (iii) on the west by the Pennine [a_5] axis (uplifted Trias).

The inclinations of the Tertiary unconformities developed in the Ipswich, Woodbridge and Felixstowe areas (Boswell, 1927; 1928) indicate progressive tilting of the Chalk formation to the east.

The N.W. - S.E. AXIS CONCEPT propounded locally by Boswell (1915) must be modified. (i) Contours constructed for the surface of the Palaeozoic floor (Bullard et al., 1946) suggest, if anything, a N.E. - S.W. trend. (ii) Data from Woodland (1946, Figs. 9, 10) suggest the 'axis' is better regarded as the point of intersection of the N. - S. (Gt. Yarmouth) and the E.N.E. - W.S.W. (London Basin) downwarps of Tertiary deposition. (iii) Further data from Woodland (1946, Figs. 7, 8) show a deep trough (-150' O.D.) of Pleistocene deposition running N.E. - S.W., at right-angles to the proposed 'axis'.

The MAIN STAGES IN THE ORIGIN OF THE BASIN were: (i) the formation of the Paris and N.W. German Basins and the setting-off of the North Sea Basin within the East Anglian - Brabant massif and the Erkelenz axis inthe immediate pre-Jurassic; (ii) the foundering of the southern margin (East Anglian - Brabant massif) during the Lower Cretaceous; (iii) the re-establishment of the southern margin (Weald - Artois axis) and production of present limits during the Tertiary.

The MAIN STAGES IN THE SUBSEQUENT DEVELOPMENT were:

(1) DIESTIAN (= Lenham Beds) base of Pliocene.

(a)
Palaeogeography:- The extent of the sea is indicated by the Suffolk Bone

(No.5)

Bed (with Oligocene - Miocene boxstones), the Lenham Beds, and the Diestian deposits of Belgium (found at depth in Holland).

Assignation of benches in S.E. England is not straightforward. The fauna at Lenham, resting on a 200ms (600') bench, is (Reid, 1890, p.52) an 80ms (40 fathoms) one, therefore corresponding to a 280ms (840') bench. (Contrast Wooldridge and Linton, 1939).

(b) Palaeoecology:- The fauna contains a mixture of Miocene and Pliocene elements (Miocene/Pliocene mollusca at Lenham; Miocene foraminifera at Diest).

Depth Zones: Littoral (0 - 10 ms); Epineritic (15 - 50 ms) - glauconitic sands, Terebratula perforata and Ditrupa subulata (60 - 120 fathoms according to Reid, 1890); Infraneritic (50 - 200 ms) - (i) unfossiliferous glauconitic, and (ii) foraminiferal, sandy, micaceous clays. Compare Voorthuysen (1954) with Reid (1890).

Lenham	: 0 - 10 ms	;	at least 40 fathoms
Antwerp	: 15 - 50 ms	;	less than 40 fathoms
Utrecht	: 50 - 200 ms	;	40 fathoms

Reid (1890, p.51) suggested that the sea was warmer to the S.W. and quoted the occurrence of the northern form Nucula cobboldiae in Holland, as supporting evidence.

(c) Tectonics:- Subsidence has brought the basal Diestian to -700 ms O.D. at Zaandam since that period. Elevation has brought it to 200 ms above O.D. south of Antwerp. This is a difference of about 1,000 ms in 200 kms.

Sedimentation at Zaandam (142 ms) and at Antwerp (12 ms) suggests contemporaneous (Diestian) subsidence at Zaandam. However, there is not yet any significant difference between sedimentation at Zaandam (a tectonic low) and at Zeist (a tectonic high) where Diestian deposits are 130 ms thick.

(2) SCALDISIAN (= Coralline Crag)

(a) Period limited by episodes of marginal erosion.

(b) Compare Voorthuysen (1954) with Reid (1890).

Coralline Crag : 0 - 10 ms ; 40 - 60 fathoms

(c) Tectonic comparisons impossible because Diestian and Scaldisian infraneritic foraminiferal faunas are indistinguishable at present.

(No.5)

(3) POEDERLIAN (= Red Crag) base of Pleistocene.

(a) Marine communication closed to south; regression during Butleyan, with lagoonal foraminifera, Strellus beccarii common.

(b) Lagaaij's work on Bryozoa (1952) indicated that the Poederlian (littoral = Amstelian (neritic). Realisation of this equation has led to a simplification of both the stratigraphy and the correlation with East Anglian deposits.

(c) Differential subsidence between Zeist (high), 35 ms of deposit (now at -135 ms O.D.), and Zaandam (low), 196 ms of deposit (now at -390 ms O.D.) probably resulted from movements of an extension of the Rhine graben.

(4) ICENIAN (= Norwich and Weybourne Crags, etc)

(a) Northward migration of the southern shoreline.

(b) Fauna affected by increasing cold and freshwater influences in the Basin. General disposition of depth zones continues as before.

(c) Differential subsidence continues at Zeist, 50 ms (at -85 ms O.D.) and at Zaandam, 230 ms (at -160 ms O.D.).

The Stowmarket depression, running N.E.-S.W., is probably mainly of this age, although deposits at the bottom of the trough may be Poederlian. Woodland (1946) suggested that the depression is synclinal because the water yields are less along the axis (as would be expected in a syncline owing to compression of fissures along that line). Thicker deposits of the later Glacial Sands and Gravels (underlying the Lowestoft Till) are found along the line of the Stowmarket depression, suggesting that it continued to operate into post-Icenian times. [The Lowestoft Till, in general rests on a diversified surface in which the main depressions, etc correspond with those of the present topography.]

APPENDIX

Estimates of Sedimentation and Subsidence in the Basin.

Mesozoic and Tertiary .... 7,500 ms (2×10^8 yrs), i.e 4 mm/100 yrs

Pleistocene and Holocene .. 300 ms (600,000 yrs), i.e. 5 cms/100 yrs

Riss to Recent .... 80 ms (200,000 yrs), i.e. 4 cms/100 yrs

Holocence .... 22 ms (20,000 yrs), i.e. 11 cms/100 yrs

Historic (tide gauges) .... 0.15 ms (50 yrs), i.e. 30 cms/100 yrs

[cf. Steers, 1953, 'The Sea Coast' 5cms/100 yrs for S.E. England].

(No.5)

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EXPLANATION OF FIGURES - see p.5.

FIG. 1. Structural Limits. (Umbgrove)

FIG. 2. Diestian. (Voorthuysen)

FIG. 3. Poederlian. (Voorthuysen)

FIG. 4. Icenian. (Voorthuysen)

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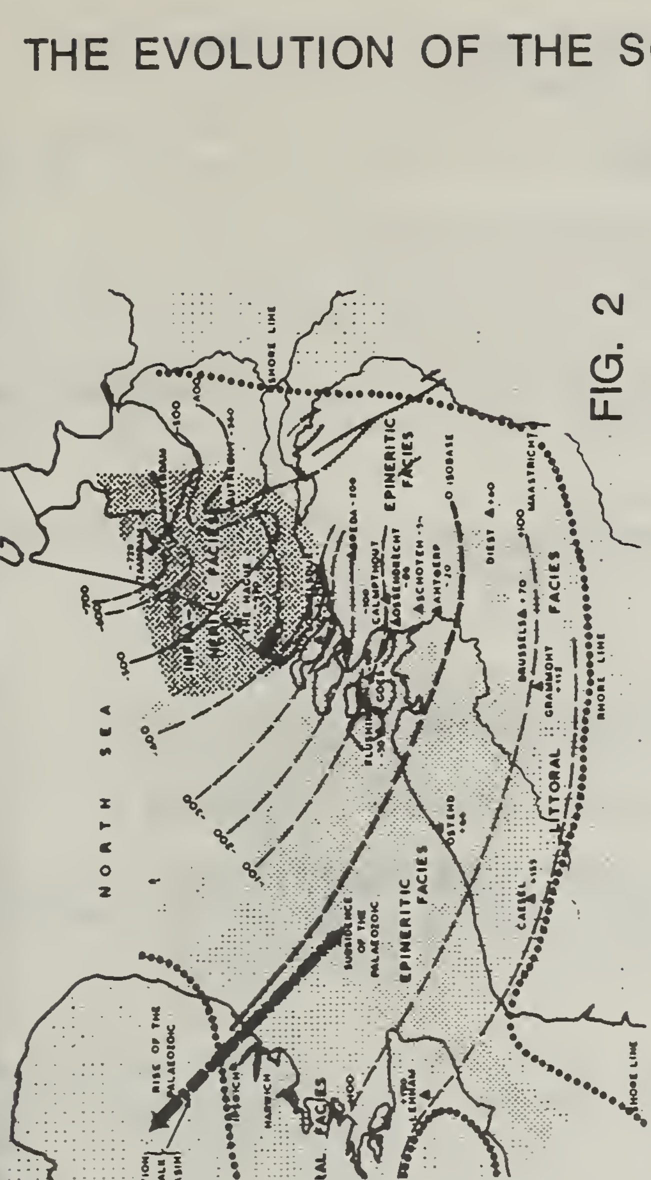

FIG. 2

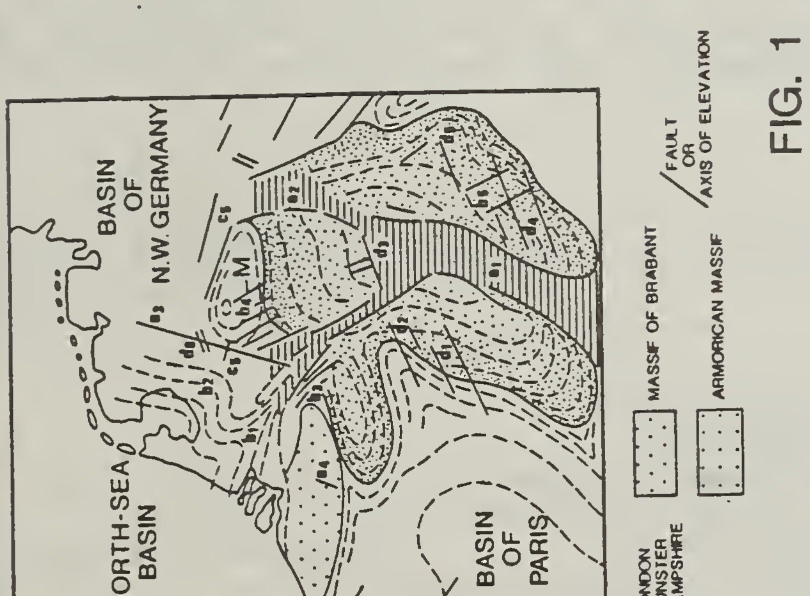

FIG. 1

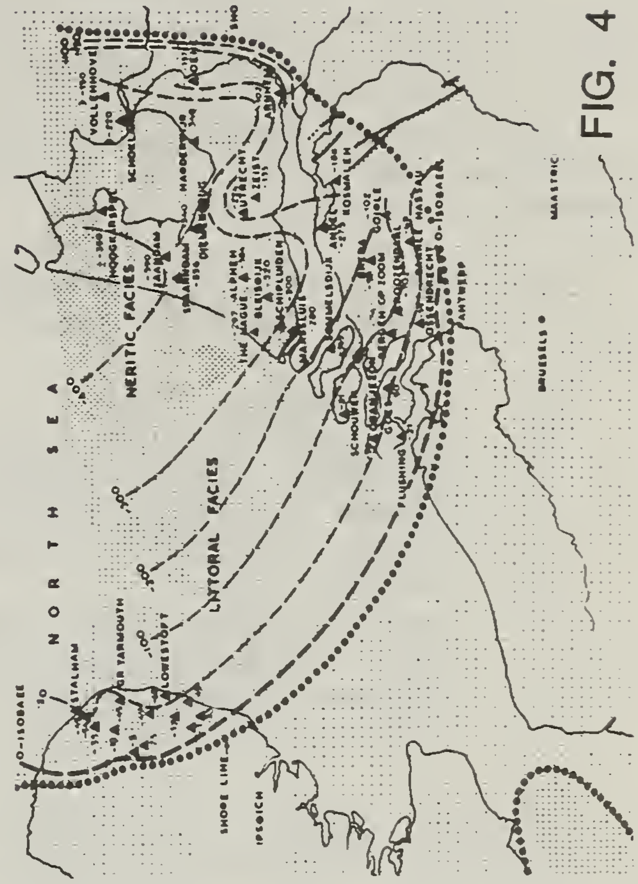

FIG. 4

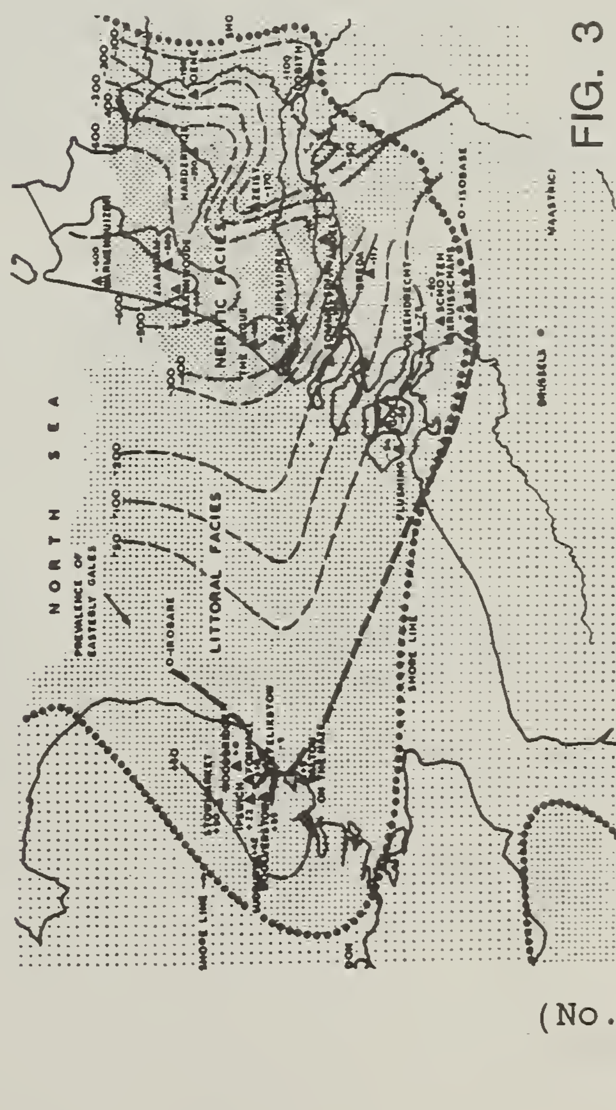

FIG. 3

(No.5)

THE GLACIATIONS AND INTERGLACIALS OF EAST ANGLIA; A SUMMARY AND DISCUSSION OF RECENT RESEARCH

by R.G. WEST

From QUATERNARIA, VOL.2, 1955, pp.45-52

Summary by A.J. Martin

Dr. West's paper is a concise survey of the state of research and knowledge concerning the Quaternary deposits of East Anglia and wider aspects of correlation.

Current views on the general Quaternary succession in East Anglia have been summarized by Baden-Powell as follows:-

9. Hunstanton Till
8. Nar Valley Clay and March Gravels
7. Gipping Till and Little Eastern Glaciation
6. Hoxne interglacials
5. Lowestoft Till and Great Eastern Glaciation
4. Corton Beds
3. North Sea Drift (including Norwich Brickearth and Cromer Till - the latter in places divided by the Mundesley Sands)
2. Cromer Forest Bed
1. Weybourne Crag

Recent work on the Till fabrics and the orientation of erratics has confirmed this succession and equates the period of deposition of the Gipping Till with that of the Main Chalky Boulder-Clay of the Midlands (recently described by Shotton). In East Anglia there were three main ice advances (Hunstanton Till not considered here). New work on the interglacial deposits between the Till sheets, using largely pollen analysis techniques and a reconsideration of the typology of the Palaeolithic implements, has resulted in the following broad correlation:-

Correlations with N.German Glaciations & Interglacials (WOLDSTEDT - 1954)	Deposits in E.Anglia	General Names of Glaciations & Interglacials in E.Anglia
	(Solifluxion Deposits)	
Emmian Interglacial	Cambridge & Ipswich Interglacial Deposits	Ipswichian Interglacial
Saale Glaciation	Gipping Till	Gipping Glaciation
Holstein Interglacial	Hoxne & Clacton Interglacial Deposits	Hoxnian Interglacial
Elster Glaciation	Lowestoft Till, Corton Beds & Cromer Beds	Lowestoft Glaciation
Cromer Interglacial	Cromer Forest Bed	Cromerian Interglacial

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The above table is an over-simplified statement of facts, but is a good starting point for further stratigraphical and correlative work, especially with the continent.

In East Anglia there are still many deposits to be worked on and fitted into the correlative scheme. These include the Westleton Beds; divisions of the Cromer Till; Contorted Drift; Corton Beds; 'cannon-shot' gravels; Cromer Ridge; Morston Raised Beach; Nar Valley Clay; March Gravels and the Hunstaton Till.

IF POSSIBLE MATERIAL FOR PUBLICATION IN THE BULLETIN

SHOULD BE TYPED. IF IN MANUSCRIPT IT SHOULD BE LEGIBLE.

ALL MATERIAL FOR PUBLICATION SHOULD BE SENT TO

THE EDITOR, 317D UPPER RICHMOND ROAD, PUTNEY, S.W.15.

BIBLIOGRAPHY OF EAST ANGLIAN GEOLOGY

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SOURCES cond.

Suffolk Naturalists' Society: Transactions .... (T.S.N.S.)

Yorkshire Geological Society: Proceedings .... (P.Y.G.S.)

SYSTEMS OF ABBREVIATION

Author Date Title Journal [volume], (part), pages

e.g. West, R.G. 1955. The Glaciations & Interglacials of East Anglia; a summary and discussion of recent research. Q., [2], 45-52.

SPECIAL NOTE

In a compilation of this kind it is inevitable that errors and omissions should occur. Notice of these should be sent, with full details, to B.M. Funnell Esq., 93 Norwich Road, New Costessey, NORWICH

B.M. Funnell (February, 1956)

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(No.5)

PARAMOUDRA CLUB BULLETIN

No.6. February, 1957. Editor: G.P. Larwood

1956 EASTER FIELD MEETING

Locality: Caister St. Edmunds (Frettenham Lime Co.) - N.G. 239046.

Horizons: Upper Chalk, zone of Belemnitelia mucronata, & Norwich Crag Series.

UPPER CHALK. Six continuous lines of flint were visible in the white, irregularly jointed chalk. These were numbered from top to bottom and the intervals between them measured: I - 4'0", II - 10'8", III - 3'6", IV - 3'3", V - 3'0", VI. There was also a discontinuous line - IIa - about 4'0" below II. Total depth about 30'. Top line of flint 1'0" below top chalk at point of measurement.

The following were collected at the horizons indicated:-

1 Ventriculites (IV-V); 1 Bryozoan (VI-); 1 Echinocorys scutata (VI-); 1 Cretirhynchia arcuata (III-IV); 1 Cretirhynchia sp. (VI-); 1 Magas pumilis (III-VI); 1&3 Kingena lima (IV-V, VI-); 1&2 Carneithyris carnea; 1 C.gracilis; 2 C. ?variabilis (V-VI); 1 ?Carneithyris (IV-V); 1 Pecten (Neitnea) sexcostatus (V-VI); 2 Spondylus dutempleanus (VI-); 1 Gervillia (Pseudoptera) coerulescens (VI-); 1 Ostrea incurva Nilsson, form (VI-); 1&2&2&4 Belemnitella mucronata Schlotheim var ?minor Jeletzky (II-VI, IV-V, V-VI, VI-); 1&2 Belemnitella ?mucronata (V-VI, VI-).

NORWICH CRAG SERIES. A Basement Bed of large flints, with poorly preserved shells, is overlain by about 2'0" of sands and gravels succeeded by about 3'0" of clay. Overlying deposits of doubtful age are present, they consist of gravels resting on sands, in all about 9'0": the junction between the sands and the clays tends to be undulating. ?The distal end of an 'elephant' femur was found in gravel about 1-2'0" above the chalk. Mr. A.J. Martin subsequently found a portion of 'elephant' tusk in a similar situation.

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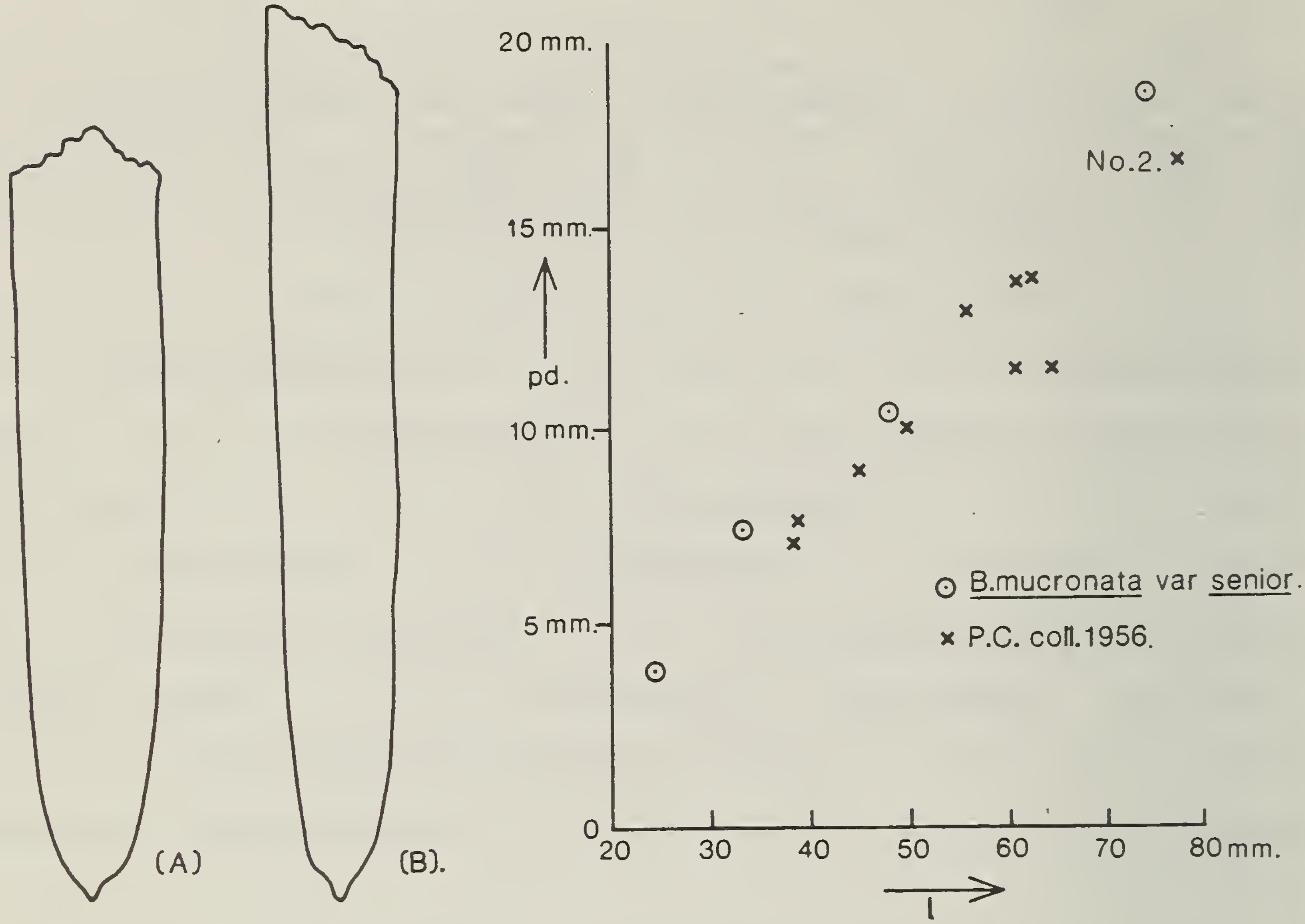
B.M. Funnell (Aug. 1956).

(No.6)

THE NORWICH CHALK BELEMNITIDAE

GENERA: The Belemnites of the Norwich Chalk belong to the genus Belemnitella.

SPECIES: D. Sharpe (1853), following Schlotheim, distinguished two species of Belemnitella from the Upper Chalk:- B.mucronata and B.lanceolata.



(A) B.mucronata var senior (after Jeletzky, 1948)

(B) B.mucronata var minor (after Sharpe, 1853) [see Jeletzky, 1951].

Sharpe's description and attribution of mucronata specimens (with strongly marked vascular impressions and sub-central alveoli) to B.mucronata was correct. His description of non-mucronate specimens (with weak or absent vascular impressions and central alveoli) does not coincide with Schlotheim's B.lanceolata and their attribution to that species was incorrect.

(i) Many specimens from the Actinocamax quadrata zone of the Upper Chalk, subsequently determined as Belemnitella lanceolata, on the basis of Sharpe's erroneous description, can in fact be referred to B. pracecursor Stolley 1897,

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see Jeletzky 1948.

(ii) However, specimens from the zone of Belemnitella mucronata of the Upper Chalk, determined, on the same basis, as B.lanceolata, are almost certainly distinct from B.praecursor and B.mucronata, and must, for the present, be designated Belemnitella sp. (Wright, C.W. & E.V. 1950).

(iii) Schlotheim's original B.lanceolata is now referred to the genus Belemnelia; it is not found lower than the horizon of the Trimmingham Chalk, where it is abundant.

VARIETIES: Of the three species at present claimed for the Norwich Chalk (Jeletzky, 1951) [B.mucronata, B.langei and Belemnitella sp.], B.mucronata has been assigned two varieties. These are B.mucronata var senior Nowak 1913, which is found in the lower portion of the zone of B.mucronata, and B.mucronata var minor Jeletzky 1951, which is found in the upper part of the zone of B.mucronata.

The two varieties differ in proportions, B.mucronata var minor being more slender.

The following measurements were made, and the profile ratio calculated, in an objective attempt to distinguish the two varieties:-

(i) length (l), measured from the apex to the posterior end of the ventral groove,

(ii) profile diameter (pd), diameter of profile measured at the posterior end of the ventral groove,

(iii) profile ratio (PR), the ratio of l to pd.

I. B.mucronata var senior (growth stages) [measurements from Jeletzky, 1948, pl.20, fig.2b]

l	pd	PR
24.5 mm	4.0 mm	6.13
35.5 mm	7.5 mm	4.43
48.5 mm	10.5 mm	4.62
74.5 mm	18.5 mm	4.03

II. B.mucronata var minor (as the ventral groove is not shown on Sharpe's figures which Jeletzky [1951] designated as holotype, a close match was made with a specimen fromthe 1956 Paramoudra Club collection. No.2, which was selected, is approximately 0.50 mm narrower posteriorly and a very small fraction wider anteriorly.

l	pd	PR
78.0 mm	16.5 mm	4.73

These figures show (a) that the guard of B.mucronata var senior becomes progressively less slender as growth proceeds, and (b) that the adult guard of B.mucronata var minor is more slender than that of B.mucronata var senior. Figures obtained in this way are best compared graphically, plotting pd against l. In this way the more slender young stages of B.mucronata var senior can be distinguished from the adult stages of B.mucronata var minor.

The results, for the Paramoudra Club 1956 collections, are plotted graphically above. It can be seen that for the most part the plots fall outside the zone of variation shown by the growth stages of B.mucronata var senior and are probably referable to B.mucronata var minor from the upper part of the zone of B.mucronata zone of Jeletzky (1951).

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SHOULD BE TYPED. IF IN MANUSCRIPT IT SHOULD BE LEGIBLE.

ALL MATERIAL FOR PUBLICATION SHOULD BE SENT TO

THE EDITOR, 55 PERCY PARK, TYNEMOUTH, NORTHUMBERLAND.

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PARAMOUDRA CLUB BULLETIN

No.7. December 1957 Editor: G.P. Larwood

THE DIFFERENTIATION AND CORRELATION OF EAST ANGLIAN PLEISTOCENE DEPOSITS : A REVIEW OF RECENT RESEARCH

Notes from the Presidential Address - 1956

B.M. Funnell, B.A., F.G.S.

MARINE DEPOSITS [Baden-Powell, D.F.W. (1955)]. "The Correlation of the Pliocene and Pleistocene Marine Beds of Britain and the Mediterranean". P.G.A., [66], 271-292.

Abstract: Deposits of different ages are differentiated on the basis of the arrival and extinction of molluscan species. Thus the CORTONIAN is distinguished by the following arrivals - Cardium tuberculatum, C. exiguum, Venus verrucosa, V. gallina, Gibbula magus, Nassa reticulata; Turritella communis becomes common. (Tapes decussatus is omitted as Reid (1890) records it from the Weybourne Crag). The Cortonian includes the last occurrence of the following extinct species - Nucula cobboldiae, Purpura incrassata and Nassa reticosa. The MARCH GRAVELS are distinguished by the following arrivals - Skenea planorbis, Tellina tenuis, and include the last occurrence of the extinct species Tellina obliqua (one valve only).

Deposits of the same age are correlated by (a) the common arrival and extinction of molluscan species, and (b) the matching of alternating 'cold' and 'warm' faunas. Thus many species become extinct at the end of the CORALLINE CRAG - ASTIAN, and many arrive in common in the RED CRAG - CALABRIAN. Nassa reticulata arrives and Turritella communis becomes common in the CORTONIAN - TYRRHENIAN. Discrepancies are explained by southward migration (late arrivals in the Calabrian from the Coralline Crag), and northward migration (late arrivals in the Cortonian, March Gravels and Holocene from the Astian and Calabrian). Discrepancies in climatic correlations are explained as the result of steeper temperature gradients caused by variations in the Gulf Stream Drift.

Comment : The RED and ICENIAN CRAGS have previously been differentiated on the basis of the decreasing proportions of extinct and southern shells. As the two different methods have not yet been applied to the same deposits no anomalies have arisen. The present method involves the selection of significant species from a larger number whose occurrence is probably governed mainly by ecological conditions. This, as with the introduction of hypotheses of climatic fluctuation as a basis of correlation, may lead to circular argument; arguing from geological age to specific range and back again to geological age. Any scheme of correlation is likely to produce discrepancies; it remains to be seen whether the discrepancies involved are capable of the most satisfactory explanation.

INTERGLACIAL DEPOSITS [West, R.G. (1956)]. "Quaternary Deposits at Hoxne, Suffolk". Phil. Trans. Roy. Soc. [B.239], 265-356.

Abstract : Differentiation and correlation of interglacial deposits is here based on the identification of a floral sequence by an analysis of the pollen content. The same species may be ingredients of all the interglacial deposits but their relative abundance and order of occurrence differ in each. Thus the HOXNE INTERGLACIAL SERIES differs from the CROMER FOREST BED SERIES which has relatively high Pinus (Pine) and Picea (Spruce) throughout, low Corylus (Hazel) and no Abies (Silver Fir). The sequence of non-tree pollens differs also. The Hoxne Interglacial Series also differs from the HISTON ROAD DEPOSITS (near Cambridge) which have high values for Carpinus (Hornbeam) in the early part of the sequence, a small percentage of Abies and in a mixed-oak forest phase dominant Quercus (Oak), with Tilia (Lime) and Ulmus (Elm) rare, Hedera and Ilex absent. The HOXNE INTERGLACIAL SERIES itself is characterised by (a) an Abies zone after a temperate deciduous forest phase, (b) the occurrence of Azolla filiculoides Lam. It is correlated with the similar occurrence of a coniferous forest phase with dominant Abies following a mixed-oak forest phase in interglacial deposits at Clacton and St. Cross South Elmham, near Bungay. The Cromer Forest Bed, Hoxne and Histon Road deposits show sequences similar to the continental pre-Elster, Elster-Saale and Saale-Weichsel deposits respectively.

Comment : These determinations are a considerable improvement on those made earlier by other methods. However, for an indication of the inherent difficulties see Duigan, S.L. (1956), Q.J.G.S., pp.383-388.

GLACIAL DEPOSITS [West, R.G. and Donner, J.J. (1956)]. "The glaciations of East Anglia and the Midlands : a differentiation based on stone-orientation measurements of the Tills". Q.J.G.S., [112], 69-91.

Abstract : The method of differentiating and correlating glacial tills which is used here is based on the identification of the direction of flow of the depositing glacier. This is done by measuring the direction of about one-hundred stones from the till, and finding the preferred orientation, which gives the direction of flow of the glacier. Thus a CROMER ADVANCE (Cromer Till and Norwich Brickearth) with a general SSE movement, a LOWESTOFT ADVANCE (Great Chalky Boulder Clay or Lowestoft Till) with a regional W to E movement fanning out N and S, and a GIPPING ADVANCE (Gipping Till) with a SE movement have been distinguished.

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Comment : These determinations are independent of previous methods. The results correspond closely with those obtained by Baden-Powell (1948) based on the matrices and erratics of the tills. Note, it is not possible to separate the Hunstanton Boulder Clay from the Gipping Advance on this basis.

B.M.F. (June, 1957)

CRETACEOUS SETTING OF EAST ANGLIA

J.M. Hancock, B.A., F.G.S.

"La craie du Norfolk ressemble plus à celle des Comtés du Nord qu'à celle du bassin de Londres" - Barrois, 1877.

Introduction : Throughout the Cretaceous period East Anglia formed a positive area of stability. To the north and south were regions which were submerged by the sea earlier, sank more rapidly, and to some extent were more strongly affected by contemporary earth movements. The stability of East Anglia is reflected in the facies of the rocks in the area. Sometimes the East Anglian region shows differences from both the regions to the north and to the south, and at other times it acted as a faunal barrier. Most commonly it was the position of an east-west line of demarcation between a northern and a southern facies.

Such a stable area as a demarcation line between facies is familiar in Jurassic sedimentation under the name 'axis'. During the Cretaceous these axes were much less common, and this one in Norfolk, which I propose to call the Icenian Axis, is much the most prominent in north-west Europe. In the British Isles the submarine sandbank along the Beer axis, described by Smith (1957), is on a minute scale by comparison, for both the Beer axis and the neighbouring Branscombe and Charlton axes only affect the lithologies very locally. The Branscombe axis does however act as a faunal barrier, particularly to echinoderms (Spencer 1913). Outside Britain another Cretaceous example is the Merlerault axis in Perche (Dangeard, 1943).

Neocomian Stages : At the beginning of the Cretaceous East Anglia was a land area. The eastern part was made up of Lower Palaeozoic sediments, the western of Jurassic sediments, whilst between the two there was probably a strip of Carboniferous.

To the south fresh-water Wealden sands were forming. It is probable that pockets of Wealden deposition originally extended well north of the present limit of Oving near Aylesbury. Thus at Potton

(Bedfordshire) examples of the Wealden tree fern Tempskya schimperi Corda have been found in (?Aptian) Woburn Sands.

To the north marine deposition began early in Lincolnshire and Yorkshire. Both counties have Berriasian marine sediments although the Russian-type ammonite fauna makes correlation difficult between the earlier Neocomian stages and their type areas in southern Europe.

With land in East Anglia, Spilsby Sandstone deposition in Lincolnshire and Speeton Clay deposition in Yorkshire, it might be supposed that the Spilsby Sandstone represents the nearer shore sediments of material derived from the East Anglia-Midlands upland. In fact the Spilsby Sandstone has a staurolite, kyanite, garnet and epidote assemblage of heavy minerals. These minerals could not possibly have come from the south but may be derived from Scotland. The Yorkshire-Lincolnshire basin of deposition must have been bounded to the west by a north-south coastline, so that Spilsby sediments were either brought directly by eastward-flowing rivers or brought south by marine and longshire drift.

A similar situation existed during the formation of the Sandringham Sands. The sea had now (probably late Hauterivian) advanced southwards into East Anglia, but there is still no evidence of detrius coming from erosion of the London Platform. The current bedding in the sands has roughly easterly and westerly dips. There is staurolite and kyanite in the heavy mineral assemblage. Possibly the sediment is derived from a former southerly extension of the Spilsby Beds, or possibly there was a continuation of the drainage pattern that produced the Spilsby Sandstone but extending further south-east.

The overlying Snettisham Clay becomes sandy as it is traced southward, the change taking place around West Newton, some two miles south of Sandringham. This is the same area which has rapid changes in the Albian facies.

Aptian : It is during the succeeding Aptian stage that the marine invasion in southern England crossed the Icenian Axis to join the northern sea, though overlap by the Gault hides any Aptian Beds for part of the distance south-west of Methwold. In the north is the ferruginous Carstone, in the south the Woburn Sands, sometimes clean enough for glass sands. The type of sediment formed over the axis can be seen from the Lower Greensand at Upware. Here there is a conglomeratic and sandy limestone, some patches of which are packed with fossils, both indigenous and derived. These thin axial deposits are probably the condensed equivalent of the whole of the Carstone and Woburn Sands, whose accessory mineralogy is of the same far travelled species.

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Albian : The Albian provides the most striking change in lithology of a stage continuous across the axis. The southern England dark grey Gault Clay extends north as far as Roydon. But north of Stoke Ferry the upper part becomes more calcareous and lighter in colour, so that it has sometimes been mistaken for Chalk Marl. At Roydon the upper part of the Albian includes a pale yellow grey limestone bed. At Dersingham the whole stage is more calcareous although still a marl rather than a limestone; the lower part has become red and harder. From Ingoldisthorpe northwards Red Chalk is the only Albian sediment.

The faunal differences between the Gault and Red Chalk are greater than the faunal lists indicate. Only Neohibolites minimus (Miller) is common in both formations. The other two common Red Chalk fossils - Rectithyris biplicata (J. Sowerby) and large Inoceramus fragments, are scarce in the Gault. A number of brachiopods (e.g. 'Terebratula' capillata d'Archiac) are common between the Red Chalk and the Shenley Limestone - the only British Albian limestone south of the Icenian Axis.

The colour of the Red Chalk really does reflect a high iron content - up to 40%, although generally only 8-10%. It almost certainly results from the drainage of a laterite area.

Upper Cretaceous - Norfolk is one of the few areas without a true Chalk Basement Bed and there is a marked lithological break between the Red Chalk and the White Chalk. Between the two there is sometimes even a 'soil' bed. This contains amongst its heavy minerals a blue amphibole and a colourless pyroxene unknown in the earlier sediments of the region and implying a change in the drainage system, or the exposure of a new source rock.

It is sometimes thought that the Icenian Axis had no effect on the Upper Cretaceous, the Chalk being continuous across it. In fact it marks changes in both the lithologies and faunas.

The soft Chalk Marl of Cambridgeshire disappears south of Roydon. Around Grimston and Roydon the base of the Chalk becomes hard, and at Hunstanton forms a 'sponge' bed, the 'sponges' being irregular cylindrical concretions. The Cenomanian thins over the axis but it is quite unknown if this is due to a condensation of the whole stage or if the lower part of the stage is missing. Ammonites become rare and continue so in Lincolnshire and Yorkshire. The brachiopod fauna changes. Ornatothyris obtusa (J. de C. Sowerby) of the upper part of

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the Cambridge Greensand is replaced by _O_. aff. _pentagonalis_ Sahni at Hunstanton. At Speeton in Yorkshire species of _Cocinnithyris_ are found in the green grey marly chalk immediately above the Red Chalk proper. This is a genus not known with certainty before the Middle Cenomanian.

The faunal differences are most marked in the Senonian, when the Yorkshire fauna shows closer affinities with north Germany than south England. The northern fauna makes its appearance in Norfolk, and the absence of Senonian Chalk in Lincolnshire is less of a handicap than one might expect in tracing the geographical changes across the Icenian Axis. Here I shall confine myself to a consideration of a few of the echinoids, but the changes can also be illustrated by sponges, crinoids, ammonites, lamellibranchs and brachiopods.

Striking examples are:

Micraster cor-anguinum Klein - Common on its own zone in southern England and occurs in Norfolk, but in Yorkshire it is "one of the rarest fossils in its own zone" (Rowe, 1904). Similar remarks apply to _Micraster cor-testudinarium_ Goldfuss.

Infulaster excentricus (Rose) - In southern England very rare; known from the _M. cor-anguinum_ zone of Hampshire and the ?_O. pilula_ zone of south Wiltshire; in Cambridgeshire and Norfolk it ranges from the _M. cor-anguinum_ to the _B. mucronata_ zone; it is recorded from the _T. lata_ zone of Lincolnshire; in Yorkshire it is a common fossil in the _H. planus_ zone and ranges into the _M. cor-testudinarium_ zone but it not yet known from higher horizons.

Hagenowia rostrata (Forbes) - In southern England this is a rare fossil from the _M. cor-anguinum_ to the _G. quadrata_ zone, though fragments of it are common in the lower part of the _G. quadrata_ zone in Sussex. In Norfolk it ranges from the _M. cor-anguinum_ to the _B. mucronata_ zone but its frequency is unknown to me. In Yorkshire it is an abundant fossil in the _M.cor-anguinum_ zone, replacing it as the zonal indicator. Its vertical range here is from the _M. cor-testudinarium_ zone to the highest chalk preserved in the _O. pilula_ zone.

J.M.H. (December, 1957)

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PARAMOUDRA CLUB BULLETIN

No.8, March 1958 Editor: G.P. Larwood

HUTTON, SMITH AND LYELL IN NORFOLK

Notes from the Presidential Address - 1957

A.J. Martin, B.Sc., F.G.S.

James Hutton, William Smith and Sir Charles Lyell all visited or stayed in Norfolk during their lifetimes and their connections with the county are of some interest. The reasons for their visits differ, and, of the three, Smith spent the longest time in the county. Their visits in no way coincided and more than a century elapsed between Hutton's arrival in Norfolk in 1752 and Lyell's last recorded visit in 1869.

Hutton, in 1752 at the age of twenty-six, having graduated from Edinburgh and Leiden, set about improving the family farm in Berwickshire. He heard that the best farming practice of the time was to be found in Norfolk and he stayed in the county for nearly three years from 1752 to 1754. He went first to Yarmouth and later moved to Norwich, where, under the guidance of John Dibol he "enjoyed the company of the most intelligent farmers". Among other things he was impressed by the high standards of ploughing in the county and on his return to Berwickshire took with him both a Norfolk plough and ploughman.

Baily and Macgregor both state that it was during his stay in Norfolk that Hutton's interest in geology was aroused. In a letter (1753) he states how he "looked inquiringly into every pit, ditch and river bed". While in Norfolk he visited other parts of the country on foot making similar observations. It should be emphasised that Hutton visited Norfolk as a farmer and his edited writings give no indication how, if at all, his later ideas were influenced by what he had seen in the county.

Smith came to Norfolk as an engineer with the job of draining and improving the marshland north of Yarmouth and improving the sea defences. He visited the county for long periods between 1801 and 1809 and lived in Norwich from 1805 to 1807, during which time he examined many local exposures.

In 1806 he had printed in Norwich a work describing the draining of land at Woburn Abbey and in the same year started on a work entitled "Description of Norfolk, its Soil and Substrata" which in manuscript was called a "Topographical Fossilological and Agricultural Description of Norfolk". This was widely advertised in the city in

1806 but from various letters and diary entries it is evident that it was still unfinished in 1819 and presumably remained unfinished. A few copies of the first fifty-six pages were printed and a copy of these was seen by Samuel Woodward in the early 19830's but there is now no known copy in existence and Cox has referred to it as "Smith's lost work". It is unlikely a copy will be found but Smith's written comments would be of great interest since his annotated section, entitled "Geological View and Section of Norfolk", and his map of the county, both published in 1819, show that he was familiar with, and had recorded many details of Norfolk geology. His other local work was a report on improving the marshland in the Waveney Valley around Diss.

Smith's visit to the county undoubtedly increased his knowledge of stratigraphy and in his major work, "Strata Identified by Organised Fossils", nearly all the Upper Chalk and Crag fossils illustrated are of specimens he collected around Norwich. He probably knew and influenced many of the local naturalists during his stay in the county.

Lyell, like Hutton, first visited Norfolk when his interest in geology was just developing. In 1817 he stayed with Dawson Turner in Yarmouth and a number of Lyell's letters written from Yarmouth show that he had speculated on the relatively recent changes in the Yare Estuary. He visited Norfolk frequently, knew many local naturalists and made many observations on Norfolk geology. These were included in his Principles of Geology and formed the subject of several papers. During his visits he made large collections of Chalk and Crag fossils, and on one occasion studied paramoudras, presenting his results tothe British Association in 1838. At the age of seventy-two (1869), with his nephew, he walked along the cliffs from Aldborough to Sheringham, recording sections and paying particular attention to the Forest Bed. Unlike Hutton and Smith, Lyell came to Norfolk specifically to study the geology of the county.

Lack of detail makes it difficult to assess how much the work of local naturalists influenced, or was influenced by, the work of Hutton, Smith and Lyell. The have attracted many biographers and most of their known manuscripts have been edited. Possible local sources of information however are almost untouched and may yet yield more details on the connections between these three geologists and the early development of Norfolk geology.

(A.J.M. Jan. 1958)

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(No.8)

PARAMOUDRA CLUB BULLETIN

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CRETACEOUS FLINT

Presidential Address - 1958

S.V.Bell, B.Sc., F.G.S.

Geologists have always been concerned with the problem of the origin and formation of flint. Early workers on the Chalk were particularly puzzled by the fact that flint, almost pure silica, should be found so abundantly in an almost purely calcareous sediment. Many early theories on the origin of flint were based on the idea that the Chalk was a deep sea deposit accumulated in a fashion similar to the present day Globigerina oozes. However, it is now thought that the Chalk was deposited in water less than 300′ deep.

At a very early date the term "flint" was applied to, and generally restricted to, siliceous rocks in the Chalk. The modern view is that the terms "chert" and "flint" are synonymous. Pettijohn (1957), writes "while the term flint antedates the term chert, useage favours the latter as the proper designation of the materials to which both terms have been applied". However, the term flint is so firmly established in British literature on the Cretaceous that it would be difficult and confusing to replace it with the word chert.

The Occurrence of Flint

Flint occurs as discrete nodules, or in tabular masses parallel to the bedding of the Chalk or as veins that cut across the bedding. Nodular flint, which has a mammillary surface, occurs in a great variety of shapes. This type of flint often has a hollow centre which may be partly filled with quartz crystals or chalk. Larger flint nodules are commonly perforated. The paramoudras of the Norwich area are an unusual form of large, perforated flint. They occur as vertical, irregularly cylindrical masses commonly up to three feet in length, and occasionally much longer, and up to two feet in diameter with a large, central, longitudinal hollow filled with hard chalk. Smaller nodules of flint tend to be spherical varying from forms with a large central cavity to nodules which are solid flint throughout.

Tabular masses of flint may reach 12 inches in thickness and can be traced laterally over quite long distances. They may have been formed by the joining together of nodular flints to produce extensive masses of great irregularity.

In the stratigraphic sense flint is normally restricted in its occurrence to the Middle and Upper divisions of the Chalk, but the precise horizon at which flint first appears in a particular section varies considerably. Jukes-Browne (1893) and Hill (1911) recorded flint in the Lower Chalk of Dorest and Yorkshire respectively.

Genesis of Flint

Flint is now generally regarded as a deposit formed by chemical action. Pettijohn (1957) states that chert and flint are the most common chemical siliceous sediments. If we accept that flint is chemically formed there are three major problems to be solved. These are the source of the silica, the layering of flint, and the time of formation.

The Middle and Upper Chalk of the British Isles is a very pure limestone which contains very little silica in a free or combined state. However, the occurrence of sponge spicules throughout the main mass of the Chalk seems to provide a source of silica from which flint has been formed. Throughout the literature dealing with the Chalk there are many references which indicate that the original silica can be removed from sponge spicules or may be replaced by calcite or glauconite. Jukes-Browne (1889) noted that siliceous sponge spicules may be replaced by calcite or that the silica may be removed altogether leaving a hollow space - as in the Malmstone of Surrey. A contemporary of Jukes-Browne, W. Hill (1911) recorded that on the fractured surface of specimens of Middle and Upper Chalk one can sometimes see hollows; each of which, from their shape, must have at one time contained the spicule of a sponge.

Many flints have cavities filled with "chalk-meal", material that can only be the original chalk sediment. Chalk-meal is frequently very rich in siliceous sponge spicules and silicified remains of Bryozoa, Ostracoda, Foraminifera, echinoid spines, etc. These organic remains may be found protruding into the cavity from the inside of the nodule. Since every nodule does not contain a cavity but may be silicified throughout and since thin sections of completely silicified nodules reveal relic structures of Foraminifera and sponge spicules it is reasonable to assume that silicification is gradual and progressive. However, there is no evidence that silicification is taking place at the present time therefore the supply of silica must have become exhausted. This tends to support the hypothesis that the silica was derived from sponge spicules.

Much macro-evidence for progressive silicification is available. This includes the casts and moulds of whole echinoids, brachiopods and molluscs. The very detailed work of

Sellas (1880) and Cayeux (1929) shows that flint has been formed by the silicification of chalk-sediment. Hatch, Rastall and Black (1952) consider that no other hypothesis fits the observed facts.

The theories of the mechanism of the transfer of silica from sponge remains to the accumulations known as flint usually envisage changes in hydrostatic pressure, alkaline solutions and differential solubilities to greater or lesser degrees. The more important contributions in this field are by Wroost (1936) who states that the replacement of chalk by a silica gel following the downward percolation of carbonated waters is mainly controlled by differential solubilities. Twenhofel (1950) makes the unsubstantiated statement that transported silica seems to be mostly in the form of a hydrophyllic colloid that is not very sensitive to electrolytes. This is not in agreement with the experimental results of Moore and Maynard (1929) who found that colloidal silica is precipitated by electrolytes as in sea water and that calcium-bicarbonate is a powerful precipitant of colloidal silica. There seems to be little agreement on this matter but the work of Moore and Maynard appears to provide an acceptable answer to the problem.

That transport of silica took place in the colloidal form seems likely from the available facts. The majority of sponge spicules are composed of organic opal - a form of colloidal silica. In thin section flint is revealed as minutely granular chalcedonic silica, itself an intimate mixture of opal and minute quartz grains, indicating the presence of colloidal silica in flint.

Time of Formation of Flint

Flint veins with a cross-cutting relationship to the bedding of the Chalk are almost certainly tectonic in origin. Their occurrence seems to be restricted mainly to areas that have suffered some degree of earth-movement. Richardson (1919) concluded that "vein flint is directly related to tectonic movement, hence [is emplaced] subsequent to the deposition of the Chalk and epigenetic". On the other hand Wallich (1880) considered that vein flint is syngenetic filling fissures in the Chalk. This conclusion does not accord with the field evidence.

The age of the more common nodular and tabular flints is not so certain. They must be pre-Tertiary since they are found in the basal conglomerates of the Eocene. In addition, the formation of flint is pre-Miocene because bands of flint nodules and tabular flints are folded with the Chalk.

In their papers on the subject Wallich and Jukes-Browne infer a syngenetic origin for flint, while Oakley (1944), Hill (1911) and Abbott (1893) consider that flint is epigenetic in relation to the Chalk.

In the Lower Chalk there occur sponges that have had their siliceous framework broken down and replaced by crystalline calcite. In thin section it appears that the silica has tended to accumulate in the central areas of the sponge and that replacement by crystalline calcite has taken place towards the margin of the sponge. In one particular section the calcite crystals are quite large. It is not unreasonable to assume that similar conditions prevailed in the Middle and Upper Chalk thus indicating one way in which nucleii for silica accumulation can be formed. The earliest time at which such replacement can have taken place is penecontemporaneous and accumulation of silica from the sediment round nucleii formed in this manner would be epigenetic. The inclusion of whole echinoids, brachiopods and molluscs in flint suggests an epigenetic origin. Tarr (1926) considered that the inclusion of fossils within flint and the preservation of the fine details of those fossils points to a syngenetic origin for flint. He believes that silica was precipitated from sea water as a gel at the same time as the deposition of the Chalk. The preservation of fine detail results from this silica gel surrounding the recently dead animals.

The formation of flint, a variety of chert, results from the solution, transport and accumulation of silica which was derived, for the most part, from sponge spicules. The time of the formation of flint seems to be at the earliest penecontemporaneous but probably epigenetic and pre-Eocene.

(S.V.B. Jan., 1959)

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PATTERNED GROUND

A Descriptive Review with emphasis on the importance of Permafrost Features in East Anglia

Presidential Address - 1960

P.H. Banham, B.Sc., F.G.S.

Introduction

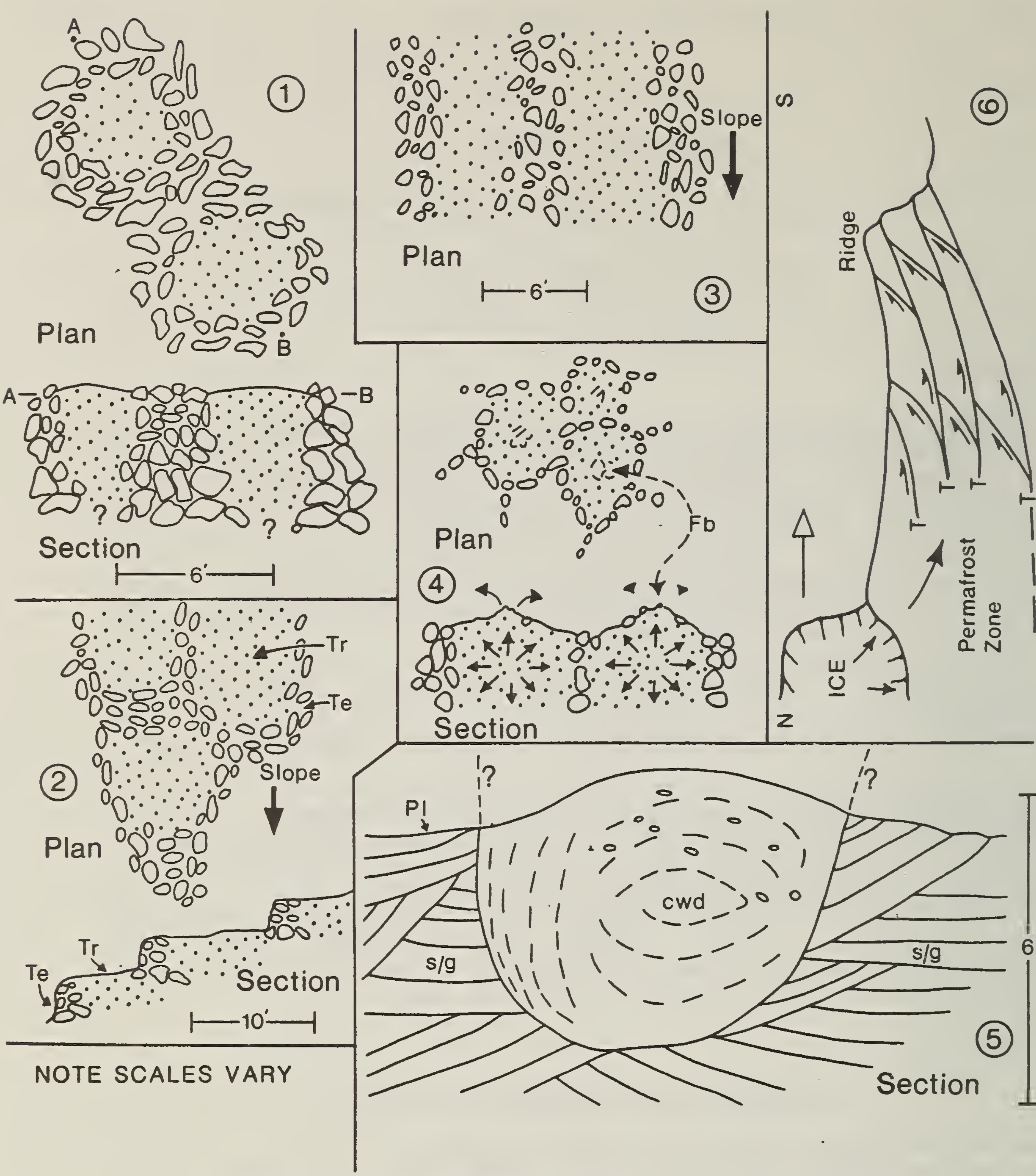
During the last four summer field seasons, while carrying out geological work on part of the Caledonian Basal Gneiss and Schist Complex of N. Southern Norway, I have had opportunity to study the active permafrost fields which occur generally above the 6,000 foot contour on the Hestbrepiggan Range of the Jotunheim Mountains, southern Norway (E.8°20, N.61°50). These freshly developed examples of patterned ground have stimulated an interest in the features possibly formed by frost action in the superficial deposits of East Anglia.

Accordingly, I have conducted a survey, both of the literature, and, in a rather limited way, of the evidence as presented in the field. A review of this work is presented here.

It is important to stress that the terms "patterned ground" and "permafrost features" are not completely synonymous. Whereas permafrost "is perennially frozen mantle or bedrock" which occurs "wherever a temperature below 0°C remains for several years" (Black 1954), patterned ground, in its broadest sense, is "a group term for the more or less symmetrical forms such as circles, polygons, nets, steps and stripes that are characteristic of, but not necessarily confined to, mantle subject to intense frost action" (Washburn 1956).

Explanation of Figures 1-6 (p.2)

1. Plan and sectional views of sorted circles
2. Plan and sectional views of sorted steps (Tr. tread, Te. terrace)
3. Plan view of sorted stripes
4. Plan and sectional views of "frost-boiling" (Fb)soil-stone polygons
5. Section of soil cracks at Mayton Hall Pit, Little Hautbois. (Pl. pit level, cwd. clay with flints, s/g. sands and gravels)
6. An ice thrusting mechanism for the formation of "end-moraines". Based on descriptions in the text of Rutten (1960). (T. thrust planes)



NOTE SCALES VARY

BANHAM PATTERNED GROUND (P.C.Bull .10,1961)

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In fact, patterned ground is a well known surface phenomenon in localities such as the arid parts of Africa and Australia, which are well outside present or recently past permafrost zones. However, in view of our situation in a recently glaciated area, particular interest in East Anglia is centred on features that have resulted directly from permafrost activity, as has most patterned ground throughout the world.

After brief descriptions of the various structural types covered by the general term patterned ground, it is intended to review the detailed origins of these features. Finally, attention will be drawn to the importance of past permafrost activity in East Anglia.

The Permafrost Environment

It is estimated (Black 1954) that, at present, 26% of the earth's surface is underlain by permafrost. The areas most affected, as one would expect, are N. Asia, N. America and Antarctica, although regions of high altitude in Scandinavia, Central Europe and elsewhere also contribute relatively small areas.

The maximum known thickess of permafrost is 2,000 feet at Nordvik in N. Siberia, although a thickness around 1,000 feet is more usual, and a depth over 100 feet is uncommon in most peripheral regions such as temperate latitude, high altitude mountain chains.

As patterned ground is developed throughout these permafrost regions it seems reasonable to conclude that its formation is intimately connected with the development of a frozen soil and sub-soil. This is made especially credible when the temperate/volume relations of water are considered. At atmospheric pressure the minimum specific volume of water is at 3.98°C. As the temperature is steaily increased the specific volume of water increases at an even rate, but, if the temperature is decreased, the specific volume increases proportionately until 0°C, when an acceleration in the rate of volume increase takes place. It is known that water freezing at 0°C in a confined space can exert pressures up to 30,000 lbs/sq.in. Below 0°C the steady increase in the volume of (solid) water continues, until, at -10°C, ice has a specific volume approximating to that of water at +20°C (68°F) (Kaye and Laby 1948).

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This fluctuation in the volume of water throughout the temperature range which affects areas of permafrost is generally held to be critical for the development of patterned ground.

Obviously, a permanently frozen surface layer will considerably affect plant and animal life, but this aspect of permafrost areas cannot be discussed except in so far as differences in the type of vegetation cover often give a remarkably good indication of the pattern shapes in the underlying soil and sub-soil (Watt 1955; Shotton 1960).

Types of Patterned Ground

Although there is no generally accepted genetic classification of patterned ground, I have adapted Washburn's (1956) purely empirical classification in which surface shapes of patterns are diagnostic.

Washburn has divided the patterns observable in permafrost regions into:

1) Circles - "patterned ground whose mesh is dominantly circular ..."

2) Nets - "... whose mesh is intermediate between that of circles and polygons"

3) Polygons - "... whose mesh is dominantly polygonal ..."

4) Steps - "... with a step-like form ..."

5) Stripes - "... with a striped pattern ..."

It is obvious that these definitions have no genetic implications and Washburn admits that many gradational types exist which tend to obscure his distinct categories.

1) Circles may occur singly or in groups and may be anything from a few inches to ten yards in diameter. As in all the other groups, both sorted and nonsorted types must be recognised. The former consist of a core of fine-grained material surrounded by a ring of boulders which usually widens with depth (Fig. 1), whereas the latter consist entirely of fine-grained material and are often detected only by means of vegetation differences between the central and marginal parts of the circle.

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A variety of sorted circle known as "debris islands" occurs on the Hestbrepiggan range. These "islands" comprise plugs of fine grained material isolated in block fields consisting of very large boulders, and probably represent early stages in the development of sorted circles.

2) Nets are considered to be intermediary between circles and polygons and a detailed description would be superfluous; both sorted and nonsorted types occur.

3) Polygons never occur singly (itself suggesting an origin involving mutual pressure), although in any one area there can be a great variation in size. Sorted polygons on Hestbrepiggan vary from miniature types, from 1-2 ins. in diameter, to larger varieties, up to 12′ across; the latter usually enclose a group of the former.

Non-sorted polygons tend to be very much larger and vary from a few feet to over 100′ in diameter. They are composed of fine grained material throughout and thus often require the development of a vegetation cover before they are easily detectable.

4) Steps rarely occur singly and are usually associated with polygons in regions where the slope of the ground exceeds approximately three degrees. Sorted steps consist of a terrace of boulders oriented parallel to the contour and retaining upslope a "tread" of much finer material (Fig. 2).

Non-sorted steps are emphasised by vegetation and usually owe their existence to a terrace of plant material which holds back a tread of fine grained material commonly free of vegetation.

5) Stripes never occur singly, are usually up to several feet wide and are sometimes of great length, with their long axes oriented down the steepest available slope. Sorted stripes (Fig. 3) consists of bands of stony material alternating with bands of finer material. Non-sorted stripes of uniformly fine-grained material are normally emphasised by the differential growth of vegetation on bands of differing chemical composition, permeability, etc. Sorted steps and stripes both occur on the Hestbrepiggan permafrost fields.

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The Origin of Patterned Ground

Although it is almost universally accepted that patterned ground in cold regions is formed in some way as a result of the repeated solid/liquid/gas phase transitions of water, the exact mechanism(s) of this process are the subject of much controversy. Washburn (1956) gives a most comprehensive discussion of possible origins.

The immediate origin of steps and stripes as the products of solifluction of circles and/or polygons down any available slope is abundantly documented and is supported by observations on Hestbrepiggan in the Jotunheim. Attention must be turned therefore to the ultimate origins of circles and polygons.

The relevant hypotheses are of two kind:

1) those that involve the dominant importance of ice or ice and water action in the sub-surface, and,

2) those that mainly involve the action of surface and sub-surface water.

1) Ice-action hypotheses

The process of multigelation (repeated freezing and thawing) was invoked many years ago to explain patterned ground. It is maintained that, during this process, in a mixture of fine and very coarse-grained material, such as might result from physical weathering and/or erosion of a cold land surface, the fine-grained material would absorb most water because of its higher capillarity. Subsequent freezing of the ground would thus result in a maximum volume expansion in places having most fine-grained material. This, in turn, would result in the radial and upward thrusting of stones, both within and without the fine-grained material. During the following thaw, the fine-grained material, being cohesive, would contract to its original volume leaving the stones in the positions to which they had been thrust during freezing.

The upward expulsion of earthenware spheres on the freezing of a water super-saturated sand has been demonstrated in the laboratory (Washburn 1956, p.839) and the evidence in favour of ice thrusting seems to be fairly conclusive. The main objections are that in many places the process would be very slow due to the infrequence of the

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freeze-thaw cyle (once per annum) and that sorted cirlces and polygons <u>do</u> occur in stone fields where no really fine-grained material exists.

The hydro-static pressures set up by the progressive freezing downwards of the top of the thawed layer above the "permafrost table" has been cited as being capable of frost heaving on a large scale. The main difficulty here, is that, once having established a most efficient upper confining layer the mud under pressure must be forced through it before the desired features can be produced. Furthermore, a water impervious zone is not always present even in permafrost areas. It is thought, however, that many stratal involutions in permafrost regions are produced by this "cryostatic pressure".

Contraction due to thawing, and possibly drying, of previously frozen terrain is said to be capable of producing a system of polygonal cracks by virtue of the pressures set up during shrinkage. As thawing proceeds stones would be liberated from the confining mud and would tend to fall into the cracks. On re-freezing, the central core of fine-grained material would expand, and this pressure, together with gravity effects, is said to be sufficient to force the stones down into the cracks - thereby setting up a type of convective cell. Whether this type of convection in the solid takes place or not it is certain that cracks, often several feet wide, do develop in permafrost areas. Very often they fill with water and freeze - a process which tends to widen the original crack even further ("ice-wedging"). These cracks on final melting would fill up with material from above, and this is thought to be the origin of the "soil wedges" which are so common in old permafrost terrains.

2) <u>Water-action hypotheses</u>

An hypothesis exploiting the known density differences of water (liquid) at various temperatures postulates that the inevitable temperature differences between the various layers in a thawing permafrost top layer would be sufficient to instigate "convective overturn"* of water saturated materials. Stones would be swept upwards and outwards and would tend to concentrate at the margins of convective cells developed in fine-grained material.

[*Not true convective overturn as implied by physicists.]

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Despite the neatness of this hypothesis it has been demonstrated in the laboratory that fine grained material would have to contain at least 60% water, by volume, before it could take part in a convective overturn, even assuming that the density differences were sufficient in the first place. This state of supersaturation must be rather uncommon even in permafrost areas.

Again, as boulders are good conductors and fine-grained materials good insulators it has been suggested that, on thawing, the boulders would tend to lie in melt water depressions. As thawing proceeds laterally and downward these depressions would become connected to form melt water channels surrounding areas of dominantly finer, frozen material. In this way polygonal and circular patterns could be built up from a region of fine-grained material with randomly placed enclosed boulders. The strongest objections to this hypothesis seem to be that non-sorted patterns are not accounted for, and that, sooner or later, the drainage water would select a few dominant routes which would probably develop a dendritic pattern. On Hestbrepiggan a considerable flow of water takes place along the stony margins of polygons, and it is clear that drainage can be of considerable importance in maintaining the distinction between the coarse and fine-grained regions of the pattern by selective removal of mud from around the stones.

Although I have seen sorted circles, polygons, steps and stripes on Hestbrepiggan, as far as I am aware, non-sorted types do not occur. There appears to be a steady gradation from block fields (areas composed entirely of large boulders resulting from recent glacial activity) to well sorted polygons. My own view is that fine material beneath the boulders is injected by differential frost heaving into the boulders above forming the type of sorted circle known as a "debris-island". The next step involves the formation of more and more debris islands by the same mechanism until the stage is reached when mutual interference between lateral pressure fields takes place and the circles pass by stages into polygons. The last stage present on Hestbrepiggan involves the continued upthrust of fine material until the area consists dominantly of large central cores of fine-grained material surrounded by rings of boulders. The latter tend to remain distinct as the surface drainage continually clears them of mud.

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The development of stripes from the step stage by solifluction down a slight incline is confirmed by observations on Hestbrepiggan. Possibly the amount of fine grained material controls the initiation of solifluction features.

Finally, it is possible that non-sorted circles and polygons develop as a result of the continued upward overflow of fine-grained material until a layer of the fine grade completely overlies the original boulder field. Cracks would then develop by repeated freezing, thawing and drying to form non-sorted patterns. Although this final stage is not seen on Hestbrepiggan the rupture of summer lichen cover by winter frost expansion in the centres of the polygons is common. The type of pattern (sorted or non-sorted) produced by any mechanism(s) depends to a large extent on the nature of the material in which permafrost is developed.

Permafrost and Patterned Ground in East Anglia

For obvious reasons we should expect to find permafrost features in the British Isles. Periodically, during the earlier stages of the recent ice-age, sheets of ice spread south from polar regions, and the overall decrease in temperature facilitated the development of permafrost, and periglacial conditions must have existed over large parts of the British Isles for considerable periods.

West (1956), on the basis of pollen analyses of deposits belonging to the Hoxnian Interglacial period, has concluded that periglacial conditions proceded the Gipping Glaciation and probably also succeeded the Lowestoft Glaciation. He also cites elsewhere the occurrence of "permafrost features" (mainly involutions?) in the Gipping Till, showing that permafrost conditions were at least penecontemporaneous with that glaciation.

Varve type sediments show that, at certain periods at least, freezing was sufficiently hard to alter considerably the amounts of surface water (e.g. Whitlingham Pit 126/267077).

Patterned ground has occasionally been reported from East Anglia. Paterson (1940) described "soil-cracks" exposed in the Traveller's Rest

pit in the Observatory Gravels north of Cambridge. These structures are reminiscent of similar active phenomena around Baffin Bay. Similar soil cracks, possibly resulting from the infilling of previous ice-wedges, can be found in many pits in Norfolk; particularly fine examples occur infalse bedded glacio-fluvial deposits at Mayton Hall Pit, Little Hautbois (126/248213). In this connection, however, Yehle (1954) has suggested that many cracks are, in fact, "soil-tongues" produced by normal sub-soil leaching. The criteria which distinguish the two types of phenomena are based on the observation that in soil-tonues the normal bedding may be bent, but rarely disrupted. At Little Hautbois, however, there can be no doubt that material from ahove has filled a steep sided crack most probably developed by ice-wedging. (The specimen illustrated in figure 5 probably extended several feet vertically at one time, the upper portion having been subsequently removed by erosion and pit development.)

The clay-with-flints that fills the crack illustrated in Fig. 5 shows a series of concentric partings between micro-structural units; possibly these were formed by freeze/thaw expansion and contraction or by solid or liquid convection currents within the clay-with-flints mass.

Somewhat similar, steep-sided cracks and basins can be seen at Thunder Lane Corner Pit, Norwich (126/263102), and elsewhere, and it appears that these features are quite common. Their study in commercially developed sections could be most rewarding as the main difficulty experienced by periglacial geologists is the lack of vertical exposure; even the excavation of sections can be most difficult in a wet, frozen mixture of mud and boulders on absolutely flat permafrost fields offering very poor sites.

In the Breck of S.W. Norfolk and N.W. Suffolk at Thetford Heath, Watt (1955) has described an occurrence of non-sorted stripes, for locality see Funnell (1955, p.227); ridges of clay-with-flints alternating with furrow of sand-with-flints. The patter is emphasised by the growth of <u>Calluna</u> which is restricted to the thick soil found in the furrows. Sections of the type of pattern can be found in a pit at Munford to the north of Thetford.

In Breckland there is, apparently, a sizeable area of patterned ground which, in parts at least, is largely undisturbed by human or other agencies since its formation. It is very likely that a detailed survey would reveal many interesting examples of patterned ground. Further, it is possible that many of the meres (small ponds) which are so very numerous in Breckland owe their origin to some feature of patterned ground or permafrost action.

Shotton (1960) has described a most spectacular discovery of patterned ground in the valley of the Worcester Avon. A large area of non-sorted polygons, which often exceed 100′ in diameter, has been picked out by differential growth of crops and a photograph published by Shotton shows a pattern which is identical to a pattern photographed in Alaska and published by Washburn (1956, pl.4, fig.3). In the Midlands permafrost conditions have been invoked by Kellaway and Taylor (1952) to explain a variety of valley features.

Ice Tectonics

The development of a permafrost in a series of deposits must cause marked changes in the rigidity and shearing strength of the beds involved. The net result in East Anglia would be that loosely compacted gravels, sands and crags could act as much harder rocks and would tend to fracture cleanly under stress, whether that stress was transmitted through the solid Chalk below or through the frozen glacio-fluvial (and other) deposits themselves. In fact, at several localities in East Anglia, for instance in the Red Crag cliffs at Bawdsey (150/395355) and in the glacio-fluvial sands and gravels at Little Hautbois new pit (126/250213), clean cut fault features are visible. Usually, these features are a series of sub-parallel normal faults with varying down-thrown directions. Provided sufficient outcrops are available in any one area and that these fractures are as numerous as, on cursory examination, they appear to be,it should be possible to arrive at conclusions regarding the ice-stress system in that area. The importance of obtaining as much information of this sort as possible should be immediately obvious to those interested in the movements of the various ice-sheets. It is also possible that some "contorted beds" owe their formation to ice-movements, but cryostatic pressure and solifluction are alternative mechanisms.

Within this field of ice-tectonics is a recent paper by Rutten (1960). After detailed work on the well developed end-moraines of Northern Europe, it has been concluded that in no sense of the word are these ridges end-morainic at all. Universally they demonstrate a well ordered internal structure consisting usually of slices of well bedded, if false-bedded, sands and gravels, whereas end-moraines developing today, those that I am familiar with in Norway included, consist of a chaotic jumble of rocks surrounded by an inhomogeneous, structureless matrix of finer grained material. The bulk of the evidence, according to Rutten, favours the formation of these often extemely long and well developed ridges as the result of imbricate thrusting of the frozen soil and bedrock around the ice-sheet by stresses set up by the weight and forward mvoement of the ice-sheet itself (Fig. 6).

Rutten pertinently remarks that the plane at the base of the zone of permafrost, which, very possibly would be waterlogged, would probably be the plane of major translation. The thrust slices would come to rest at the limit of effective ice-thrust.

Once again, it would seem that our own "end-moraine" could bear investigation with this idea in mind. Chatwin (1954) gives a general account of the Cromer-Holt ridge. West (1957) has written a more detailed account of the eastern part of the ridge.

Summary and Conclusions

From the earlier descriptive and genetic discussions it should be apparent that a great deal of work remains to be done on the patterned ground which develops as a sequel to the formation of a permafrost zone at the surface. The lines along which this research, a great deal of it non-technical, could be directed have been indicated.

The extent to which the superficial geology of East Anglia has been disturbed by permafrost and ice-tectonic activity has, I am convinced, not been fully recognised yet. In this connection it would be particularly valuable to investigate the extent of permafrost disturbances in the various tills. Harrison (1957, p.299) includes a short discussion of the fundamental re-

orientation of till fabrics that has taken place in at least one of his samples from boulder clays near Chicago. However, West and Donner (1956) in their work on till fabrics and directions of ice-movement in East Anglia make no special mention of the effects of permafrost except in so far as this form of re-orientation is uncovered by the general statement that "a site was chosen at an undisturbed section of till" (p.71 op. cit.).

Such evidence as I have observed and collected concerning patterned ground and related permafrost activity in East Anglia has been very sporadic; it is hoped that this address (together with the selected bibliography) will be of some use as a reference for future workers.

Since this account was written the author and Mr. C.E. Ranson have investigated many exposures in central and north Norfolk and have seen much to support the above conclusions. Important exposures: 126/168415; 126/151123; 126/257091; 125/005333; 125/085357; 136/952009. (Sheet numbers apply to O.S. 1" Seventh Series.)

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The Geological Society of Norfolk exists to promote the study and knowledge of geology, particularly in East Anglia, and holds monthly meetings throughout the year. Copies of this Bulletin may be obtained from: The Secretary, Geological Society of Norfolk, Castle Museum, Norwich NR1 3JU.

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The illustration on the front cover is of early members of the Paramoudra Club at the City of Norwich School, Norwich, July 1950.

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No. 39A

November 1990

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EDITORIAL

This is the second of two supplementary Bulletins, (the first was Bulletin No. 38A, published in December 1988), which reprint in two volumes Bulletins Nos. 1-18 of the Geological Society of Norfolk. Bulletin No. 38A contains Bulletins Nos. 1-10, and Bulletin No. 39A contains Bulletins Nos. 11-18.

Bulletins Nos. 1-18 were originally issued in duplicated quarto or A4 format between 1953 and 1969. The deteriorating quality of the original paper, and the relatively poor quality of the duplicating method of reproduction made facsimile reproduction impossible. The entire text has therefore been re-set and the figures re-drawn or re-copied, but without alteration, (except for the correction of a few obvious typographic errors). Please do not respond to out-of-date notices of meetings, etc., or write to (former) members at out-of-date addresses!

In Bulletin No. 38A we retained the practice of the original Bulletins in inserting the original page number at the top right hand corner after the Bulletin number, and repeated them at the foot of the page. Several readers found this confusing, although admittedly consistent. In Bulletin No. 39A the original page number, (pagination is closely preserved), is placed centrally at the foot of the page, with a running page number for Bulletin No. 39A as a whole (in brackets), to the right or left of the foot of the page as appropriate. To find the running page numbers for individual original Bulletins refer to the CONTENTS listing on the outside of the back cover.

We are indebted to the School of Environmental Sciences, and in particular to Mrs Barbara Slade and Mrs Frances Randell (for word processing), Mr Philip Judge (drafting), and Ms Sheila Davies (photography) for fitting in the task of preparing these reprint volumes, amongst their numerous other duties, during the last four years. Mrs Pat Funnell kindly assisted with the task of checking the transcription of text.

B.M. Funnell
P.G. Cambridge

COVER PHOTOGRAPH (Paramoudra Club, 31 July 1951)
Back row (left to right): A.C. Jermy, A.G. Wright, G.R. Tresise, W.A. Gordon, V.F. Hunter, B. Bird, A. Rope, P.C. Crisp;
Middle row (left to right): I.J. Harrowven, J.M. Cox, J.S. Atkinson, B.M. Funnell, A.J. Martin;
Front row (left to right): D. Mickleburgh, M.E. Barton, C.R. Cox, A.P. Baggs.

DEDICATION

This reprint of Bulletins Nos. 11-18 is dedicated to the memory of <u>Colin Ranson</u> (1936-1989). Colin joined the Paramoudra Club in 1953, contributed regularly to its Bulletins (reprinted here), during the years 1965-1968, and was Editor of the Bulletins of the Geological Society of Norfolk issued in 1969.

Brian Funnell

PARAMOUDRA CLUB BULLETIN

No. 11. December 1962 Editor: G.P. Larwood

GLACIAL TECTONICS

A Review and Discussion of the Application of Tectonic Concepts to the Structures Observable in Glacial Deposits

Presidential Address - 1961

by P.H. Banham, B.Sc., Ph.D., F.G.S.

1. Introduction. In my last address to the Club I dealt mainly with the results of static (except on a small scale) permafrost conditions such as much have obtained over the most of the British Isles during at least one Pleistocene glacial phase. Evidence was presented from East Anglia and elsewhere, and it was noted that a direct comparison could be made between types of fossilised patterned ground in this country and active permafrost features of the Jotunheim mountains of Norway, in particular.

This year I intend to follow a line of research suggested by last year's concluding section: tectonic activity in present and past glaciated areas, with special reference to Norfolk. I am not concerned with attributing to virtually every glacial feature a tectonic origin of some sort. Rather, I am concerned that where tectonic features do occur in glaciated areas they should be recognised as such. What follows sets out to show what can be done with tectonic evidence once careful observations have been made and the limitations of the techniques understood.

2. Application of simple stress/strain concepts.

A. Major structures

Despite the possibly imposing nature of this heading, I wish merely to apply to structures produced in glaciated areas certain simple, tectonic concepts normally applied in orogenic areas.

In any area undergoing glaciation two broad types of stress/strain relations may be said to occur. First, that within

and beneath the ice-sheet, and, secondly, that marginal to the ice-sheet. I propose to call these the "closed" and "open" systems, respectively.

(i) The open system. Marginal to the ice-sheet an anisotropic stress field will develop as the result of the movement of the nearby ice. The major stress component (P.max.) will therefore be horizontal and normal to the ice front (i.e. parallel to the direction of fastest ice-movement). The minimum stress component (P.min.) will be vertical, as a consequence of the absence of heavy (ice or rock) hydrostatic load. The intermediate stress (P.int.) direction will be horizontal and normal to the P.max. + P.min. plane, and will be a function of the strength of the materials stressed.

The type, degree and extent of stress effects produced in this open system will depend not only on the order of P.max., but also upon the type of rocks involved and both the lateral and vertical extent of the permafrost field. This latter will itself depend upon many other factors, such as precipitation, drainage, rock porosity, temperature and speed of ice-advance (i.e. the rate at which the open system becomes closed).

Even without a knowledge of the exact conditions that obtained during any glacial phase, however, one may make a series of reasonable assumptions in order that a test case of general applicability may be established. The assumptions made throughout the following discussion are as follows:-

1) that the rocks involved are unconsolidated and, on a grand scale, structurally homogeneous.

2) that the permafrost field extends vertically for at least several tens of feet and laterally for at least several miles. (Such circumstances almost certainly applied to East Anglia during at least one phase of the Pleistocene glaciation.)

On these assumptions, and knowing that the P.max.-P.min. differential must be large, it can be predicted that the main strain features of the open system will be low-angled shear planes striking parallel to the ice-sheet and dipping down towards it. It will be realised immediately that the lower

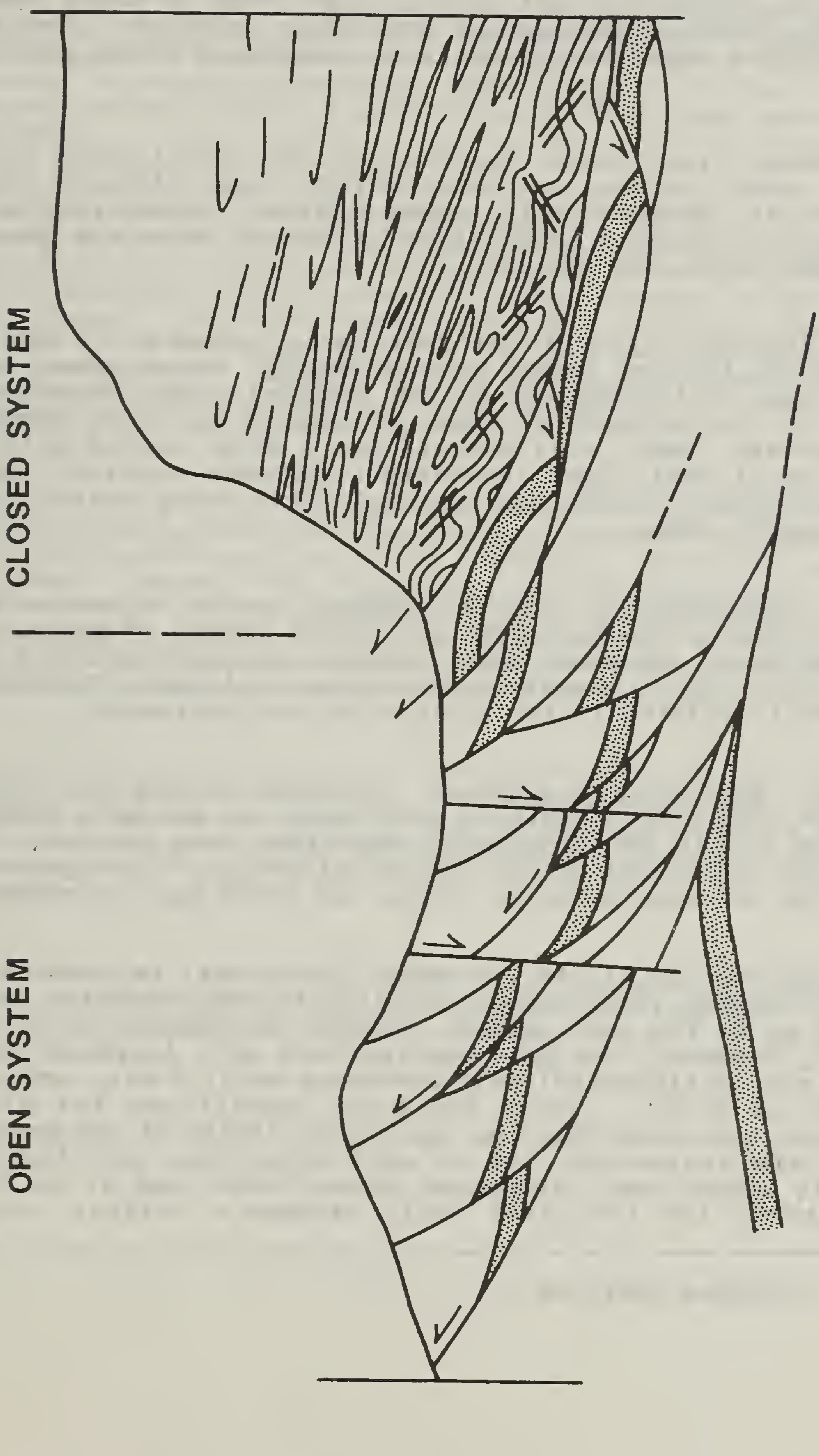

FIG.1 POSSIBLE STRUCTURES IN A GLACIAL TECTONIC AREA

Banham.P.C.Bull.II.Dec.1962

boundary of the permafrost field constitutes a plane ideally oriented for the development of such shear stresses, especially as it overlies water-saturated, unconsolidated rocks (see Fig. 1).

If these first order thrusts provide insufficient strain release, then second and even third order thrusts may be developed at increasingly steep angles, resulting in the formation of a complex imbrication structure above the plane of major translation (see Fig. 1).

One further style of deformation is probable in the open system. Once the ice ceases to move bodily, the original P.max. will decline, to be replaced by the original P.int. direction as a result of the residual stresses originally built up laterally. This secondary P.max. will operate for a short period only, but it might be of sufficient intensity to produce vertical tension cracks parallel to the ice margin, and along which normal faulting might occur.

This phenomenon of "elastic rebound" would, of course, have developed tension cracks normal to the ice margin if the original P.max. had been, although still intense, applied during a short period only. Later thrusting movements will have obscured any early normal faulting if the application was prolonged.

(ii) <u>The closed system</u>. In this sytem the stress conditions, and thus the strain resultants are entirely different from those within the previously described open system. These differences are caused solely by the influence of the hydrostatic load of the ice upon material within and below the ice-sheet.

At the surface of the ice-sheet P.min. will be vertical and P.int. horizontal (with P.max. parallel to the direction of ice-movement) as in the open system. Towards the deeper parts of the ice-sheet, however, the hydrostatiac load will increase and the P.max.-P.min. differential will descrease until P.min. approaches the value of P.int. These are ideal conditions for plastic deformation, provided that the elasticity limits of the materials stressed are surpassed. It is well known that ice has a low elasticity limit (see references given later) and it is likely that wherever the ice/dirt* ratio exceeds a certain critical

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* dirt = included detritus.

level pure elastic strain will result. It is suggested that this critical level is likely to occur at, or near, the bottom of the ice-sheet, when the ice/dirt ratio suddenly decreases (= concentration of ground-moraine material). Below this level a reversion to elastico-viscous, pure elastic or even fracture deformation will take place despite the high hydrostatic pressures.

In this way a plane approximating to the bottom of the ice-sheet will act as a more or less sharp boundary between two rather different styles of strain, and as a result, widespread shearing stresses will be developed along a plane of décollement at this level. Plastic strain above the plane of décollement will result in the formation of extremely tight, flat-lying, "overturned" folds which may eventually shear out to form a pronounced foliation. (Such a tectonic fabric is common in the glacial tills of Norfolk.)

Immediately above the plane of décollement, near the lower plasticity limit, more open shear folds, perhaps with axial plane strain-slip cleavage, are to be expected. Below the plane of décollement, larger, more open folds will be developed, together with flat shear planes approximately conformable with the plane of décollement above, and possibly associated with schuppen (reversed) thrusts. The general strike of both fold axes and thrusts will be normal to the direction of ice movement.

At a deeper level (or at the same level at another time) vertical slip planes may occur, making intersections of (approx.) 30° with the P.max. direction, and subsequent shearing along at least one of these two sets will produce tear faults. (Very many other vertical shear directions of lesser importance are theoretically possible.)

Summarily, anisotropic stress in the open system at the margins of ice-sheets may be expected to produce thrusts, possibly an imbrication zone and tension cracks. Stress in the

closed system by contrast, may produce both plastic and elastico-viscous folds, plane(s) of décollement(s) and associated schuppen structures, together with tear faults.

Having established these two discrete systems I have now the painful task of pointing out that as an ice-sheet advances, structures produced in the open system will become modified in the closed system. During any one ice advance the effects of this overprinting will not be very serious in view of the similar orientation of structures in both systems with relation to their common P.max. Discrete, later, perhaps more extensive glaciation of an earlier glacial tectonic area by a differently oriented P.max. may be expected to strongly modify, if not destroy, structural evidence of the earlier glacial phase.

B. <u>Minor Structures</u>

So far the emphasis has been largely upon the major structures produced by glacial tectonic activity. Minor structures may be expected, however, and may be of great importance in the elucidation of the glacial sequence.

Because of the increased intensity of deformation it is likely that the greatest development of minor structures will be within and below the ice-sheet (the closed system). Minor shear folds with axial plane strain-slip cleavage should be developed immediately above and below the plane of décollement, and, probably, also in association with the open system thrust planes. The intense micro-shearing which constitutes plastic flow would be expected to give discrete particles (e.g. pebbles) a preferred, directional orientation in the strain ellipsoid.

It is useful here to refer the orientation of both major and minor structures to a regional tri-axial strain ellipsoid, of whcih the axes are:-

<u>a</u> - direction of maximum shortening (horizontal, P.max. of regional stress ellipsoid),

<u>b</u> - horizontal and normal to <u>a</u>,

<u>c</u> - vertical, i.e. normal to <u>ab</u> plane

So numerous are the mechanisms which produce micro-(especially linear) fabrics, however, that very few sets of

structures can be said to have a consistent orientation in the strain ellipsoid. In fact, the only reliable evidence for the orientation of the strain ellipsoid is the strike of the major fold axes. This, of necessity, must be in b, that is normal to the direction of maximum compression (P.max. = a). A summary is given below of the commoner major and minor structures and the orientations which they prefer in orogenic tectonic areas:-

i) Major fold axes strike in b,

ii) Thrusts and schuppen structures strike in b,

iii) Vertical shear couples (tear faults) contain c and subtend an angle of (approx.) 60^{o} about a,

iv) Minor folds very commonly strike in b,

v) Discrete particles (mineral or rock fragments) may be aligned in either a or b, possibly more commonly in a.

Planar fabrics (foliations) are also developed in tectonised rocks; these may represent original bedding (unlikely in glacial deposits) or may be a tectonic banding (shear foliation).

3. Tectonics of modern ice-sheets

Evidence of tectonic structures associated with modern ice-sheets is rather scarce in the literature. As early as 1927 Slater described mud-buttes and tit-hills actually forming at glacier snouts in Alberta, but it wasn't until comparatively recently that large-scale structures were reported in association with continental ice-sheets.

In a very recent paper, Hollin and Cameron (1961) have described a remarkable "shear moraine" (a quaint term, but one which adequately links new ideas with well-known features) from the Windmill Islands (Wilkes Station) in Antarctica. This "moraine" is described as being only a few metres wide, but over 25 kms. long. It is situated along the northern margin of the main Antarctica ice-sheet and is composed of rock material sheared from bedrock beneath the ice-sheet. Measurements have been made of the rate of movement along this shear plane, which, near the ice-margin, at least, overlies dead ice, and it was

found that the active ice moved forward 69 cms. and upwards 13 cms. during approximately 6 months (July-December 1958); that is, along a plane dipping down under the ice-sheet at approximately 1:5.

Very similar shear moraines have recently been described from Greenland by Bishop (1957), Schytt (1959) and Nobles (1961), and it appears that these tectonic features play an important part in the configuration of glacial margins.

Much more work has been done concerning the properties of ice under stress, and the orientation of minor structures associated with it. Reference should be made to the following works for studies on the flow mechanics and structural development of modern glaciers and ice-sheets: Sharp (1954, 1960), Nye (1952, 1954), Glen (1958) and Kingery (1960); we are here more interested in the way in which the rocks under, around and incorporated within the ice-sheet have been deformed as a result of movements of the ice.

Donner and West (1957) have observed the emplacement of tills by the melting in-situ of the lower distal portions of glaciers in Spitsbergen. Till fabric analyses of the tills so deposited show that there are two main types of pebble orientation. First, thick bands of till have a preferred orientation of pebble long-axes in a (that is parallel to the direction of ice-movement), and, secondly, narrow band till pebbles are aligned to b.

It is thought that the closer proximity of the upper and lower ice masses defining the narrow tills causes greater shearing stress within the till, which, in turn causes the alignment of the long-axes of the pebbles in b. Theoretical support for this interpretation is deduced by Glen, Donner and West (1957) who conclude that pebbles in an ice-till matrix will tend originally to be aligned in a, but,given either a relatively long time, or a great increase in shearing stress, will tend to be aligned in b - the direction of least rotational energy. Other influences, such as the "collision factor", whose importance is proportional to the number of pebbles in unit volume of till, may determine the speed of re-alignment from a to b.

Allowing for all factors, Glen et al. conclude that pebble lineations will normally be in a, especially in thick tills, but

sometimes in b, especially in narrow tills. For other work on the orientation of pebbles in modern ice those interested are referred to Llibouty (1959), Kamb (1959) and Portman (1956, 1960).

4. Glacial Tectonics in Pleistocene Deposits

A. Major Structures

Evidence for wide-scale glacial tectonic activity is more forthcoming from the Pleistocene. An important work by Rutten (1960) in this field, concerning "thrust moraines" in Northern Europe has already been reviewed (Banham, 1960). It should be noted that Rutten considered these features to have been produced entirely during the Riss glaciation; the later Würm glaciation causing little or no disturbance because of the peculiarities of the drainage pattern of Northern Europe at that time (i.e. drainage entirely to the south).

Much work on Pleistocene glacial tectonics has been undertaken by Richter (see, for example, Richter, Sneider and Wager (1950)), who reports the thrust displacement of large masses of Tertiary (mainly Miocene and Pliocene) strata in front of at least one Pleistocene ice-sheet in North Germany. The location of the major thrust plane appears to have been controlled largely by a bed of Miocene clay, and it is possible that this layer represented the lower layer of water saturation and permafrost development.

In the Lake Agassiz Basin, on either side of the Red River, Horberg (1951) has described a most interesting series of extremely long ridges and hollows striking broadly parallel to the limit of glaciation in this region. Mainly on the evidence of magnificent air photographs, Horberg attributes these features, which, although only a few yards high and broad, altogether cover an area of over 3,500 sq. miles, to the effects of "ridging up on ice-wedges" of boulder-clay, etc. around the margin of the ice-sheet.

Exposures are, apparently, rather scarce in this area, but wherever the clays and silts involved are seen they are contorted into tight folds, often of several feet in amplitude; thus any "ridging up" was probably quite intense. Further, this particular mechanism seems to be a specific interpretation not

sufficiently supported by the evidence available. It presupposes, first, the development of a series of very numerous, regular cracks parallel to the ice-margin; secondly, the filling of these cracks with ice, and, thirdly, the ridging up of the rocks between ice-wedges, presumably as a result of pushing by the ice-sheet. Considering the variations in the stress field necessary first to open and then to close cracks and the difficulty of ridging up vertical cracks, a much simpler explanation would be to envisage the thrusting of frozen deposits up inclined shear planes. This, however, is merely a suggestion which happens to fit present arguments.

Throughout the British Isles several glacial tectonic features have been described, although usually as individual occurrences, with no general conclusions deduced. For example: Suffolk, Slater (1927b); Yorkshire, Stather (1922); Lincolnshire and Northamptonshire, Kellaway and Taylor (1953); Lancashire and Cheshire, Taylor (1958); important references to East Anglia will be considered later.

B. Minor Structures

The importance of ice-sheets (and, especially, valley glaciers) as producers of linear gouge-markings (striae) has been appreciated for a very long time. Generally, it is evidence such as this, taken together with broad topographical considerations, which is used to determine the direction of flow of ice-bodies. Striae will normally be much commoner in mountainous areas. Recently, for example, striae have been shown by Svennson (1960) to be very important in the determination of ice-movement directions during the various glacial phases suffered by the Scandes Mountains of North Sweden. Continental plains tend to be composed largely of softer rocks wich are not amenable to striation, and for this reason this fabric will not be considered further here.

The importance of the orientation of pebbles in Pleistocene tills as an index of ice movement has been realised for some time in America (e.g., Holmes, 1941), but the technique has been applied only recently in this country (see West and Donner, 1956, for bibliography). Several differing theories of till formation have been supported by the authorities using pebble orientations as the ice-movement indicators, but, generally, this lineation

has been assumed to have been in a. It will be recalled that the field work of Donner and West (1957) and the theory of Glen, Donner and West (1957) broadly justify this assumption.

Holmes (1960) has studied the evolution of till-stone shapes during their glacial transport from source to the limit of glacial activity. It has been concluded that the number of angular, wedge-shaped stones tend to decrease, and the number of ovoid pebbles to increase in proportion to their distance of ice-transport. Thus, not only is the direction of ice movement detectable by a till analysis, but also some idea may be obtained of the distance of movement by comparing pebbles from the same till over a large area. As I pointed out last year, however, the effects of redeposition, permafrost activity, re-glaciation, plants, animals and man may largely or entirely destroy a till-fabric (see also Harrison, 1957b).

Despite these destructive agencies, however, much valuable work has been carried out on ice-movement directions by till-pebble-analysis. (For example: Wright (1957) in Minnesota; Harrison (1957b) around Chicago; Holmes (1941, 1960) East of the Appalachians; Janefors (1952) in North Sweden, and by West and Donner (1956) in East Anglia and the East Midlands.) (For a recent paper on till fabric analysis, see Harrison 1957a.)

While basing ice direction movements on the assumption of pebble lineations in a, it should be remembered that neither practical nor theoretical work completely confirms this. Wherever possible, on analogy with orogenic, tectonic areas, detailed studies should be made of all available structures, both major and minor. Mr. Ranson and I have attempted such a study in North Norfolk, a summary of the results of which are included in the following section.

5. Glacial Tectonics in East Anglia

A. General

Two major works concerning the glacial tectonics of East Anglia are to be found in the literature. The first, already mentioned, by West and Donner (1956), presents evidence for three

major ice advances in Eastern England during the Pleistocene, on the basis of assumed a lineation (pebble) directions measured in a selection of apparently undisturbed till exposures.

The second important work, by Peake and Hancock (1961), contains a description of the deformation of the Upper Chalk into folded, dislocated rafts in the cliff sections between Sheringham and Trimingham on the Norfolk coast. It appears that the chalk rafts, up to at least 1,000 yds. long and 40 ft. thick (with an unknown extent inland), have been thrust from their basement and folded into asymmetrical anticlines and synclines which tend to overturn to the south. Following the major thrusting and folding, the rafts appear to have been re-thrust, the repetition of strata so formed has been clearly demonstrated by the use of chalk fossils.

Peake and Hancock are prepared to envisage dominant ice movement from the north for four main reasons:-

1) The fold axes strike between 82° in the north (Sidestrand) to 122^{0} in the south (Trimingham) - five axes measured,

2) Fold limbs dip steeply or are overturned to the south,

3) The secondary thrusts dip uniformly to the north,

4) During the thrusting no new chalk zones have been introduced into the succession, suggesting that movement has been along the strike (i.e., N-S).

B. <u>The Weybourne-Runton Area</u>

While the work of Peake and Hancock was in progress, Mr. Ranson and I, unaware of its existence, commenced a detailed study of the Weybourne-Runton area, to the north of the area studied by Peake and Hancock. This area was chosen, first, because the cliff section exposures are very good, and, secondly, because the shattered and ?rafted chalk and contorted boulder clays, etc. of this region are well known from the literature of the last eighty years or so.

In an early Survey memoir, Clement Reid (1882) attributed the folding and dislocation of the chalk and glacial deposits on the North Norfolk coast to the "enormous pressures" resulting from the movement of ice-sheets (no subsequent authority has produced a suggestion so close to what I believe to be the correct interpretation). However, later authorities objected strongly to an ice-mechanism for the emplacement of the chalk masses in the glacial drifts.

Howarth (1907), on an estimation that some of these displaced chalk blocks weighed many thousands of tons, concluded that an ice-sheet would be completely inadequate as a disrupting mechanism. He maintained, instead, that sometime after the deposition of the chalk, probably during the Pliocene, a great earthquake shattered the surface of the chalk into numerous blocks. Subsequently, a tidal wave, also instigated by the earthquake, picked up these blocks and "let them gently settle upon finely stratified beds of sand and clays without disturbing the laminations" (p.312).

Jukes-Browne (1898) considered that the Trimingham chalk masses were buried sea-stacks and caves, and Brydone (1906) in an interesting variation upon this theme, stated his belief that the chalk had under-gone three phases of deformation:-

1) Late Cretaceous folding of the chalk,

2) Elevation of the area above sea-level and marine erosion of the chalk folds to form sea-stacks and caves,

3) Glacial boulder-clay under pressure, filled these caves and clefts, forcing its way up and dislocating the chalk by so doing.

Despite the variety of hypotheses, however, it would probably be true to say that some variation of the "erratic theory" put forward by Bonney (1906), has been accepted as orthodoxy from the beginning of the century to the present day (cf., Boswell and Slater, 1923). Bonney believed that the chalk masses had fallen (others believed they were broken) from chalk cliffs or other outcrops during the Pleistocene, to be subsequently frozen into ice-sheets and possibly transported a short distance from their origin(s).

The general conclusion has been that although the ice-sheets were sufficiently powerful to transport chalk blocks, they never actually deformed and dislocated the chalk basement together with the overlying deposits. Previous workers, however, have generally omitted to consider the possibility of a permafrost zone, and the importance of glacial tectonic shearing along both the upper and lower planes bounding this zone.

The detailed conclusions of our own studies would be out of

place here. Suffice it to say that both Weybourne and Runton glacial tectonic structures are abundantly developed. Large slabs of chalk have been detached from the basement (along a plane conformable with the plane of décollement?), folded about N., - S., axes, upthrust and reverse thrust (schuppen structures) and emplaced among tills showing plastic folding and the development of a pronounced shear foliation.

At Weybourne, mainly N.W.-S.E. minor shear folds (some of which are almost certainly conjugate pairs) with associated axial plane, strain-slip cleavages, involve till, Weybourne Crag and chalk, and are almost certainly related to a plane of décollement at the top of the chalk. The fact that the upper part (2-5 ft.) of the chalk is brecciated at both Weybourne and Runton supports this conclusion.

Below the breccia, the chalk is intensely fractured by three vertical joint sets; two of these probably constitute a shear couple (15^{o} and 75^{o}) and the third is possibly an elastic rebound tension of high-angled thrust of schuppen joint set (175^{o}).

Briefly, the evidence of the orientation of both the major and minor structures seems to indicate the operation of an important early P.max. from either N.E. or S.W., with a later P.max. from the E. or W. Full details of the interpretation which Mr. Ranson and I place upon the evidence available will be published later.

6. Conclusion

With regard to East Anglia, in particular, our own work together with that of Peake and Hancock (op. cit.), suggests that a great deal of further, more comprehensive work may profitably be undertaken. Particularly, in verification of the picture of polyphasal, multidirectional ice-movements which resulted from the geologically rather restricted and geographically very broad pioneer investigations of West and Donner (op. cit.).

It is hoped that this present review and discussion of probable glacial tectonic mechanisms and structural inter-relationships will be of some value to future workers.

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PARAMOUDRA CLUB BULLETIN

No. 12 (For 1963)

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GLACIOFLUVIAL DEPOSITS AT BURGH CASTLE, SUFFOLK

by J. WESTGATE, B.Sc., F.G.S.

(Edited by C.E. Ranson, B.Sc., F.G.S.)

The susceptibility of flooding of the coastal region of Norfolk and Suffolk has necessitated the building of new sea defences and, in connection with this, some gravel pits have been reopened. These notes describe such a reopened pit at Burgh Castle (Grid Reference - TG 48180428).

SUCCESSION

6. Loamy sand with pebbles at base .... 3 to 6 feet
5. Chalky Boulder Clay (Lowestoft Till?) .. 2 to 12 feet
4. Corton Sands .... 0 to 20 feet
3. Pebble Bed .... 2 to 10 feet
2. Well bedded coarse sand .... 0 to 5 feet
1. Laminated sands and clays.

1. Laminated sands and clays. These are exposed in the floor of the quarry. They contain a few pebbles and are contorted.

2. Well bedded coarse sand. This overlies conformably the laminated sands and clays at the west end of the pond (see map) and contains much carbonaceous matter and some bones. Elsewhere this unit is missing.

3. Pebble Bed. This consists of sands and gravels in lenticular, concave-upward, cross-stratified units suggesting scouring by shifting currents followed by back-filling with coarse sediment. Tabular cross-stratification is seen in the western part of the quarry. This is produced by more persistent currents. A northerly source for the water is indicated by the current bedding.

The pebbles are mostly siliceous - flint, chert, quartzite and jasper. Ironstone concretions are common and limonite is often found cementing sand grains together. The sand is very poorly sorted and the grains are angular. This suggests deposition from currents with variable velocity and volume and/or little transportation.

4. Corton Sands. This unit is absent in the south-west of the quarry but thickens to 20 feet in the north-east. The sands are buff-coloured and are stained by limonite, especially on the bedding plane.

The lower part shows slight evidence of current bedding, but the upper part has many infilled channels containing coarser sands with pebbles, limonite ooliths and comminuted shell debris. The channels are aligned north-south.

In the upper part also there are discontinuous bands of quartz grit cemented by calcium carbonate. These bands are one to two inches thick. The bedding of the upper part of the Corton Sands is contorted near their junction with the boulder clay.

The high degree of sorting of these sands suggests that the grains were carried a long way, or were in water a long time, before deposition. Most of the grains are angular.

5. Chalky Boulder Clay. This is seen only in the north-eastern part of the quarry and rests unconformably on the Corton Sands often with a thin band of crushed chalk between the two.

The clay is brown at the base and blue at the top but is otherwise similar throughout. Chalk pebbles predominate and there are also grey flints, red sandstone, shale fragments and septarian nodules. Derived fossils from the Chalk occur.

6. Loamy Sand with pebbles at base. This lies unconformably on the boulder clay, oversteps onto the Corton Sands and rests on the Pebble Bed in the south-western part of the quarry. The Loamy Sand is especially pebbly at the base, the pebbles including foraminiferal limestone, basic igneous rocks, biotite-gneiss and quartzite.

CORRELATION

The general sequence accords well with Blake's (1890) descriptions of other exposures in the Yarmouth area.

INTERPRETATION

The lowest bed is not sufficiently well exposed to comment on. The Pebble Bed was deposited by braided streams - probably melt-water streams from an ice-sheet to the north (?Cromer Till ice).

The Corton Sands are more mature sediments which could have accumulated in or near a large body of standing water. This would account for the horizontal bedding at the base and the channel-infilling near the top. The disturbance of the upper part of the Corton Sands is probably due to ice movement above them. It is thought that the calcareous grit bands were formed

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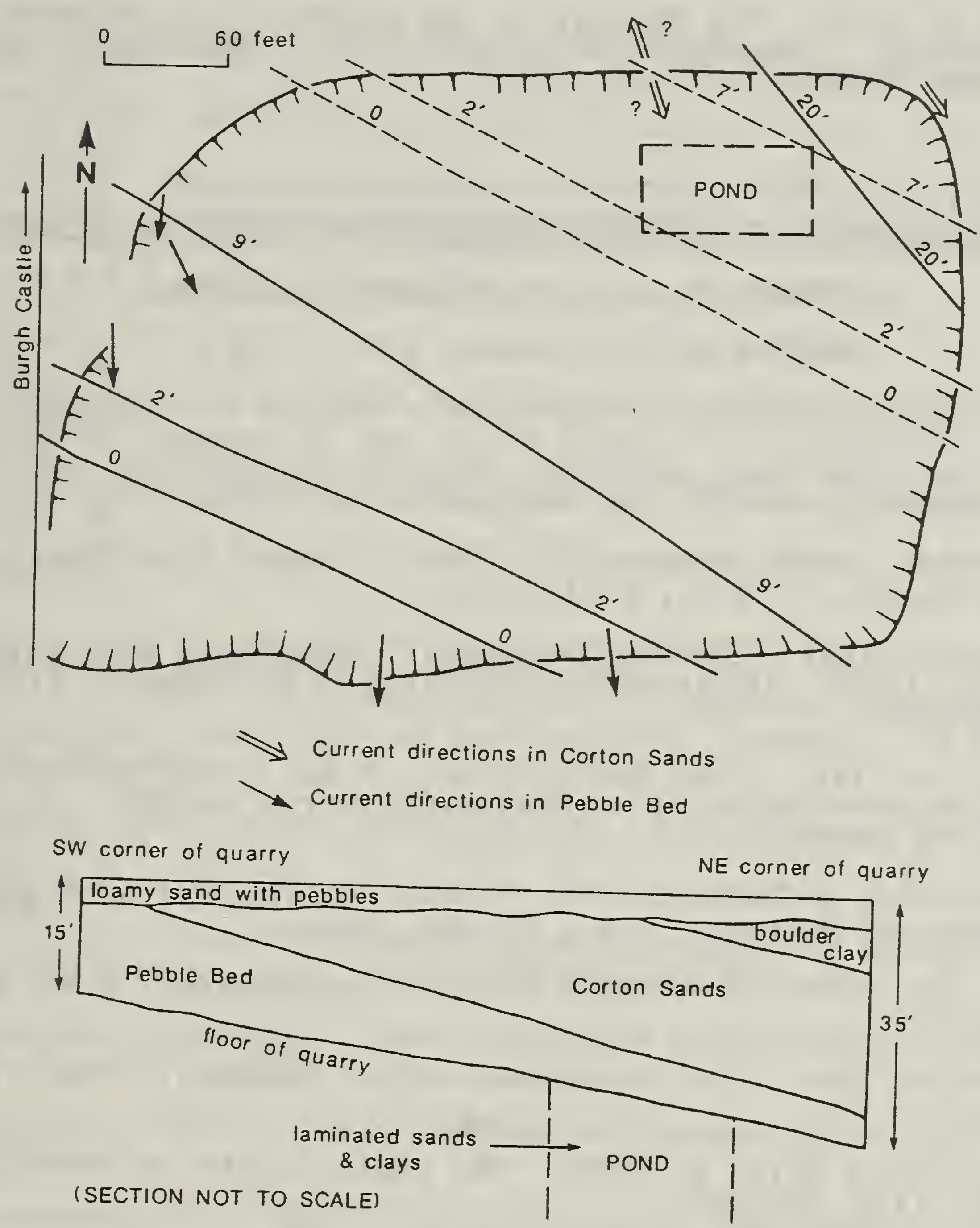
PLAN & COMPOSITE SECTION OF THE QUARRY AT BURGH CASTLE



(SECTION NOT TO SCALE)

from sediment in hollows where calcium carbonate was being deposited after solution from chalky boulder clay in the vicinity. On this evidence, it could be that the Chalky Boulder Clay (?Lowestoft Till) and the upper Corton Sands are contemporaneous.

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A BIBLIOGRAPHY OF LITERATURE DESCRIBING EXPOSURES OF BEDS DISTURBED BY ICE, PARTICULARLY IN NORFOLK

Compiled by C.E. Ranson, B.Sc., F.G.S.

This bibliography is part of a larger bibliography on glacial tectonics. It could be of use to workers on glacial deposits and the Chalk surface. Many of the exposures described in the papers listed are now obscured or destroyed.

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PARAMOUDRA CLUB BULLETIN

No. 13 (For 1964)

October 1965 Editor: G.P. Larwood

THE CROMER FOREST BED SERIES

Presidential Address for 1964

by Dr. R.G. West

The Cromer Forest Bed Series was studied by several workers in the nineteenth century (S. Woodward 1833, Lyell 1833, Trimmer 1845, Prestwich 1871, Reid 1882, 1890). The first attempt to establish a complete sequence was that of Reid in the Geological Survey Memoir of 1882: (the beds above and below the Cromer Forest Bed Series are shown).

Till
Arctic Freshwater Bed
Leda myalis Bed

Cromer Forest Bed Series	(Upper Freshwater Bed (Cromer Forest Bed *or* Estuarine Bed (Lower Freshwater Bed

Weybourne Crag
Chalk

This composite sequence was constructed from the many exposures of the Series found on the East Anglian Coast, and at no place did Reid find a complete succession (see Table 1). Reid suggested that the beds were deposited at or near the mouth of a large river, probably a forerunner of the Rhine. He also pointed out that the Weybourne Crag and the Arctic Freshwater Bed at West Runton contained floras and faunas of a cold climate whereas the beds between contained forms associated with a warmer climate.

Little further work was done until 1948 when P. Thomson (in Woldstedt, 1950) studied pollen samples from the Upper Freshwater Bed at West Runton, Duigan (1963) discovered that there had

been more fluctuations of temperature than Reid proposed. She found evidence that the Upper Freshwater Bed was formed in a climatic oscillation of interglacial type, with cold conditions at the base and more temperate in the middle. This indicated that, as the Lower Freshwater Bed also contains temperate plants, there is a cold oscillation in the middle of the Forest Bed Series.

Table 1

	CORTON	MUNDESLEY AND PASTON	SIDESTRAND	WEST RUNTON
Lowestoft Stage	Till	Till Arctic Freshwater Bed	Till	Till Upper grey-silty clay
Cromer Forest Bed Series	Tidal sediments	Tidal sediments & beach gravels	Tidal sediments	Tidal sediments
	Upper Freshwater Bed	Upper Freshwater Bed		Upper Freshwater Bed
	Rootlet Bed			Arctic Bed
	Sand and gravel	Sand and gravel	Sand and gravel incl. the so-called Weybourne Crag of Sidestrand	Sand and gravel
			Lower Freshwater Bed	Lower Freshwater Bed and Tidal Sediments incl. Crag
			Chalk	Chalk

Since 1948 most workers (Thomson, West, Duigan) on the Cromer Forest Bed Series have used the technique of pollen analysis; this contrasts with Reid's use of the macroscropic remains of plants.

Recently, more work has been started at Cambridge on the macroscopic material; and the first sedimentological studies since Reid's time have begun. West is also making a systematic analysis of all evidence of glacial and periglacial conditions within the Series. The information obtained will be compared with that from other investigations.

The main exposures of the Series are at West Runton, Sidestrand, Mundesley, Paston and Corton and recent work on these sections suggests the very provisional correlations shown in Table 1. Much further research is necessary before these correlations and the climatic fluctuations indicated by the deposits are worked out.

Conservation

The erosion of recent years has increased the willingness of local authorities and the national government to spend large sums of money on coast defences, so reducing the number of exposures of the Series. This contains the most complete sequence of deposits in Europe representing the period immediately before the first great glaciations. Because of this it is to be hoped that before any coastal defence schemes are started, local authorities will cooperate with geologists so that there is opportunity to study any deposits likely to be permanently obscured by talus or beach. This would probably mean a delay of two or three years at the most, and this time could be shortened by the provision of boreholes or mechanical excavation. One or two good exposures of the Series should be preserved so that visitors may see it in the future, but there will be difficulty in finding a method of preserving such sections of unconsolidated deposits at the cliff foot.

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QUATERNARY FIELD STUDY GROUP,

REPORT ON THE FIRST FIELD MEETING, BIRMINGHAM, 1964

by R.A.D. Markham, B.Sc.

The first meeting of the Quaternary Field Study Group was held in the Department of Geology, University of Birmingham, 13-16 April 1964.

Tomlinson (1963) contains an account of the Pleistocene of the Midlands with bibliography.

By way of introduction to the area a list of the localities visited on the excursion is given.

COVENTRY AREA AND DEPOSITS OF GLACIAL LAKE HARRISON

(14/4/64)

The Older Drift of this area is correlated with the Gipping Stage. The Wolston Series of unbedded and laminated clays and sands were deposited in Glacial Lake Harrison. Bunter pebbles are very common in the local Drifts, which may often be differentiated by the

occurrence of western (i.e. Welsh) and/or eastern (flint, etc.) erratics.

LOCAL SUCCESSION

Alluvium	
Avon Terrace 1	
" " 2	
" " 3	Newer Drift (younger Pleistocene)
" " 4	
Dunsmore Gravel	
Upper Wolston Clay	
Wolston Sand	
Lower Wolston Clay	Older Drift
Baginton Sand	
Baginton-Lillington Gravel	

Dunchurch - the village is built on the Dunsmore Gravel. Eastward, across the valley, the high ground bounding Lake Harrison can be seen.

Stretton-on-Dinsmore - north of the village, Dunsmore Gravel (includes flint; many stones with near-vertical axes) may be seen in a shallow quarry (now a refuse dump).

Wolston - (412746) the base of the Upper Wolston Clay may be seen resting on Wolston Sand on Lower Wolston Clay (c.14 ft.) on Baginton Sand (c.14 ft.) on Baginton Gravel (top seen at sides of pool).

Brandon Grounds - at the Main Pit (389758), Upper Terrace (No.4) gravel (with flint and Bunter) rests on Baginton-Lillington Gravel (penetrated by frost cracks), which lies on Keuper Marl. Lower Terrace gravel (with little flint and much Trias) has been seen below the Upper Terrace deposits. In the pit north of the road, a channel in the Baginton Gravel shows sand and organic silt (of late Hoxnian age).

DRIFTS OF THE CHESHIRE PLAIN
(15/4/64)

Chelford - two pits very close to Jodrell Bank telescope:

(i) Hargreaves and Jones Pit - sandy clays rest on pink and orange sands resting unconformably on white sands above a stiff blue clay. Ventifacts occur at the unconformity and the white sands are penetrated by frost cracks. The blue clay is under water.

(ii) Martins Pit - ? till rests on laminated clays in turn resting on white sands which are equated with those of Hargreaves and Jones Pit. At Martins Pit the white sands include an organic layer with abundant wood and fir cones. This deposit has a C_{14} date of 57,000 years and its contained flora and fauna indicate colder conditions than present day.

Beeston Castle - large sand pit showing c.20 ft. clays with thin sands and gravels, resting on c.70 ft. cross-beded sands. Shell fragments (apparently marine, cf. *Turritella*) are not uncommon.

Ellesmere (Wood Lane) - large pit in Ellesmere Moraine; deposits contorted, very stony, interpreted as a push-moraine; kettle-holes occur in this area.

SEVERN VALLEY TERRACE GRAVELS
(16/4/64)

Kidderminster - Kidderminster Terrace Deposits on Upper Bunter Moulding Sand.

Stourport - Worcester Terrace.

Eardington Forge - Main Terrace. Coal erratics common; remains of mammoth have been found here.

Buildwas - level-bedded coarse gravels on Buildwas sands.

Ironbridge Gorge - Cut by escaping waters of Lake Lapworth, gravels of Main Terrace deposited.

CORRELATION OF TERRACES

R.Severn	R.Avon
Worcester Terrace	No.1 Terrace
Main Terrace	No.2 Terrace
Kidderminster Terrace	Nos.3 & 4 Terraces (part)

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THE SURFACE OF THE CHALK IN NORFOLK

by C.E. Ranson, B.Sc.

Studies of the glacial geology of Norfolk by Dr. Banham and the writer have often necessitated detailed descriptions of disturbances of the chalk surface. Most of the structures found can be related to glacial activity.

At Weybourne, the top 5m. of the Chalk is broken into blocks set in a chalk matrix. The blocks have a preferred orientation (Banham, 1962; Banham and Ranson, 1965). This process has gone further in places to give "re-arranged chalk" (Peake and Hancock, 1961; West and Donner, 1956).

There are many records of the top 10m. or so of the Chalk being deformed to produce shallow folds and even rafts of chalk separated from the main body of the Chalk; at Weybourne, (Banham 1962; Banham and Ranson, 1965), at East and West Runtons, Overstrand, and Sidestrand (Peak and Hancock, 1961), at Taverham, at Whitlingham and Swainsthorpe (Taylor, 1865, 1866), and others.

Much solution and erosion of the chalk surface must have taken place during glacial times. The features produced by these effects are occasionally discovered accidentally in bore-holes and excavations (Funnell, 1958; Well-records in the hands of local water-engineers).

Some new evidence has been made available by the construction of the new sewers in Norwich. It seems as though much of the chalk surface consists of what is described as "crumbly chalk" and "putty chalk" by the engineers. The thickest development of this is about 15m. I have detailed records of all the bores and sections relating to this work. The cause of this deformation of the chalk is unknown; but it must be explained if a complete account of the geology of the area is to be given.

This subject needs one or more people to work on it for some time so that a large body of knowledge can be formed. I hope someone will be able to take up this work. The following references will give an adequate introduction to the subject:

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Gravity Survey Overlay. 1/4" to mile, sheet 12, Norfolk. Geol. Survey, London.

PARAMOUDRA CLUB BULLETIN

No. 14

January 1966 (For 1965)		Editor: G.P. Larwood

QUATERNARY FIELD STUDY GROUP

REPORT ON THE SECOND FIELD MEEING, DURHAM, 1965

by C.E. Ranson, B.Sc.

The Meeting was held to show workers from other areas the Quaternary deposits and features in Durham County. The Geological Survey has been engaged recently in mapping in the area and two Survey Officers, D.B. Smith and E.A. Francis, directed the Meeting.

The main points of interest for workers in East Anglia are described in this report, and a list of exposures seen is given at the end.

The Glacial Successions

In Durham County the sequence of tills and sands with gravel is comparable with that found in most parts of Britain where there are thick glacial deposits. Comparison of the sequences in Durham County and East Anglia shows this and similarity to the Midlands sequence is to be noticed.

Without suggesting any correlations, the sequences are:

Durham County	East Anglia[1]
Sands and clays	Hunstanton Till
Upper Boulder Clay	Sands and Gravels
Sands and Gravels	Gipping Till
Lower Boulder Clay	Sands and Gravels
Gravel	Lowestoft Till
Scandinavian Boulder Clay	Sands and Gravel
BED ROCK: Triassic or Permian or Coal Measures	Cromer Till
	BED ROCK: Pleistocene and Tertiary sands and clays or Chalk

((1) But see Reid, 1882; West, 1961.)

One difficulty in establishing a succession in both areas is the lack of a complete vertical sequence. In Durham County workers have made use of the considerable topographic relief and the well developed surface features to elucidate the order of events. The surface features, particularly eskers, moraines and kettle-holes, are remarkably clear. The best preserved are seen associated

with the Upper Boulder Clay (Würm age), and are more numerous and more varied than features, probably of similar age, in north Norfolk.

Those reconstructing the Ice Age history of Durham County have further evidence to cnsider: firstly, the pre-glacial topography, now covered by sands, gravels and clays, but known from numerous mine shafts and boreholes; secondly, erosion surfaces at several levels, and therefore of different ages; thirdly, at least two generations of overflow channels which are thought to be related to periods of glacial activity; and fourthly, the occurrence of marine temperate gravels between Upper and Lower Tills at Shippersea Bay, Easington.

Lithology and Structure of the Deposits

Tills (deposits thought to have been left by ice).

These vary from stiff, almost stoneless, clays and silts to stone-sand-clay mixtures.

The pebbles in the tills give some evidence of the paths the glaciers or ice sheets took before depositing their tills, and pebble orientation measurements agree with this evidence.

Contortions in the tills are apparently scarce and difficult to see. The reasons for this could be (1) that the tills, being composed largely of Coal Measures shales and sands, contain little or no pale coloured component, so making contortions obscure (for contrast with East Anglian tills see Chatwin, 1961, plate VIIB); or (2) that the tills may have been deposited in such a way that contortions were either mostly destroyed or never formed in large numbers.

Mr. P. Beaumont, of the University of Durham Geography Department, has been working on the tills, and his studies have included the identification of erratics, pebble orientation measurements, mechanical analyses and X-ray diffraction analyses of the clay fractions.

In most places, bed rock is overlain by stony, sandy clay, and in one place a section in supposed tills has a strong resemblence to a soil profile. In trying to discover whether these phenomena are natural soils, weathered tills, soils

developed on tills or more or less unaltered tills, Beaumont has measured the acidity, iron and carbonate content and the concentration of organic matter through suspected profiles. Comparison of these measurements with those in known soils will help in the interpretation of these beds.

E.A. Francis of the Geological Survey has been investigating the microfabrics of the three lower Tees tills at Low Rockliffe (nat. grid ref. NZ 313086).

Sands and Gravels

These have received little attention so far. They show a wide variety of sedimentary structures: ripple drift bedding, many types of cross stratification, laminar bedding, alternating laminae of sand, silt and clay and poorly sorted kame and esker gravels. Post-depositional changes have given rise to slumping, loading and boudinage structures, and ice movement has caused deformation of bedding. The environments of deposition seem to have been those of ice sheet margins, sub-glacial streams and proglacial outwash fans and lakes. The Edderacres lake deposits of laminated silts and sands, in which the laminae are each a few millimetres thick, may result from seasonal, probably annual, deposition of laminae. The flora and fauna, if any, of this supposed proglacial lack will be of particular interest to those working on interglacial sites in other parts of Britain.

Dating the Deposits

D.B. Smith writes (in litt. 14/5/65) "With regard to dating, I regard the Scandinavian drift as of Lowestoft age, the Lower Boulder Clay as Gipping and the equivalent of the Drab of Holderness, and the Upper Boulder Clay as late Würm and the equivalent of the Hessle and Hunstanton Tills. I know that this disagrees with Penny's time associations, but I think that he is wrong in dismissing the Kelsey Hill gravels as an erratic and if he is wrong, then these gravels indicate (as do the shelly gravels at Shippersea Bay) a temperate interval twixt Drab-Purple on the one hand, and the Hessle on the other".

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Exposures

These are all easy of access, quarries require permission for entry. National grid references follow each locality name.

Greenside Quarry (NZ 155625)

(2) Poorly sorted gravels
(1) Well sorted sands with cross stratification and ripple drift bedding. Occasional gravel beds.

Castle Eden Dene Mouth (NZ 457408)

(5) Upper Boulder Clay
(4) Sands
(3) Lower Boulder Clay
(2) Gravelly sands in pockets
(1) Magnesian Limestone.

The cliff section northward to Warren House Gill shows the same succession in patches.

Warren House Gill (NZ 448424)

(7) Upper Boulder Clay
(6) Gravels
(5) Sand
(4) Lower Boulder Clay
(3) Silt (loess?)
(2) Scandinavian Boulder Clay
(1) Magnesian Limestone.

Between Warren House Gill and Horden Dene (NZ 446436) the sands between the tills cut down to rest on the Magnesian Limestone. The sands are here gravelly and locally composed entirely of broken up Magnesian Limestone.

Castle Hill Quarry (NZ 130637)

(3) Upper Boulder Clay?

(2) Ill sorted gravels, partly disturbed with the Upper Boulder Clay
(1) Well sorted sands and gravels, esker seen in section.

Coxhoe Quarry (NZ 334365)

(2) Lower Boulder Clay (equivalent of Single Till)
(1) Magnesian Limestone.

Durham Quarry (NZ 290417)

(3) Wear terrace gravels
(2) Stony clay. (Upper Boulder Clay?)
(1) Sands and Gravels. (The western end of the quarry has several parallel ridges of badly sorted gravel 20 feet high and 60-90 yards across).

Shotton Brick Pit (NZ 400403)

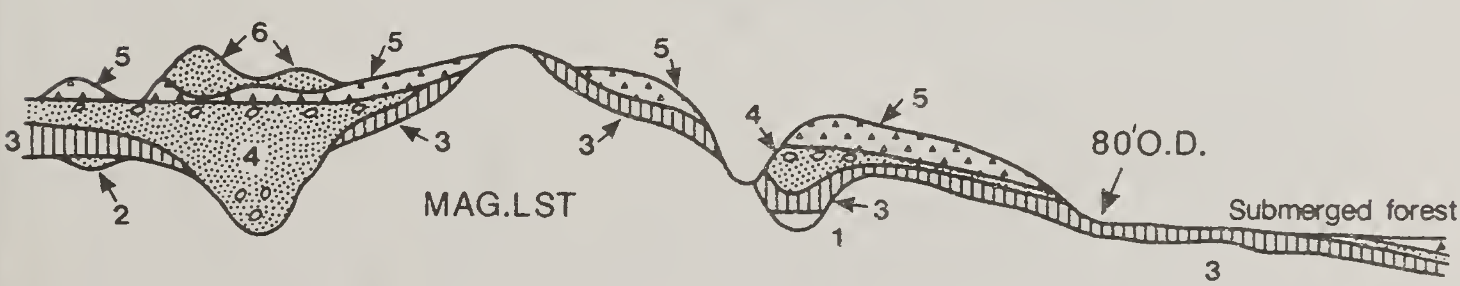
(3) Solifluxion Bed - clay and silt from Lower Boulder Clay?
(2) Laminated Clays and Silts. These are part of the Edderacres lake clays
(1) Lower Boulder Clay.

Low Rockliffe (right bank of R. Tees) (NZ 313086)

(8) Grey-brown till
(7) Laminated silt
(6) Sands
(5) Brown till
(4) Boulder bed
(3) Red till
(2) Grey till
(1) Trias.

Microfabric analyses show that each of the three lower tills have roughly the same orientation of particles.

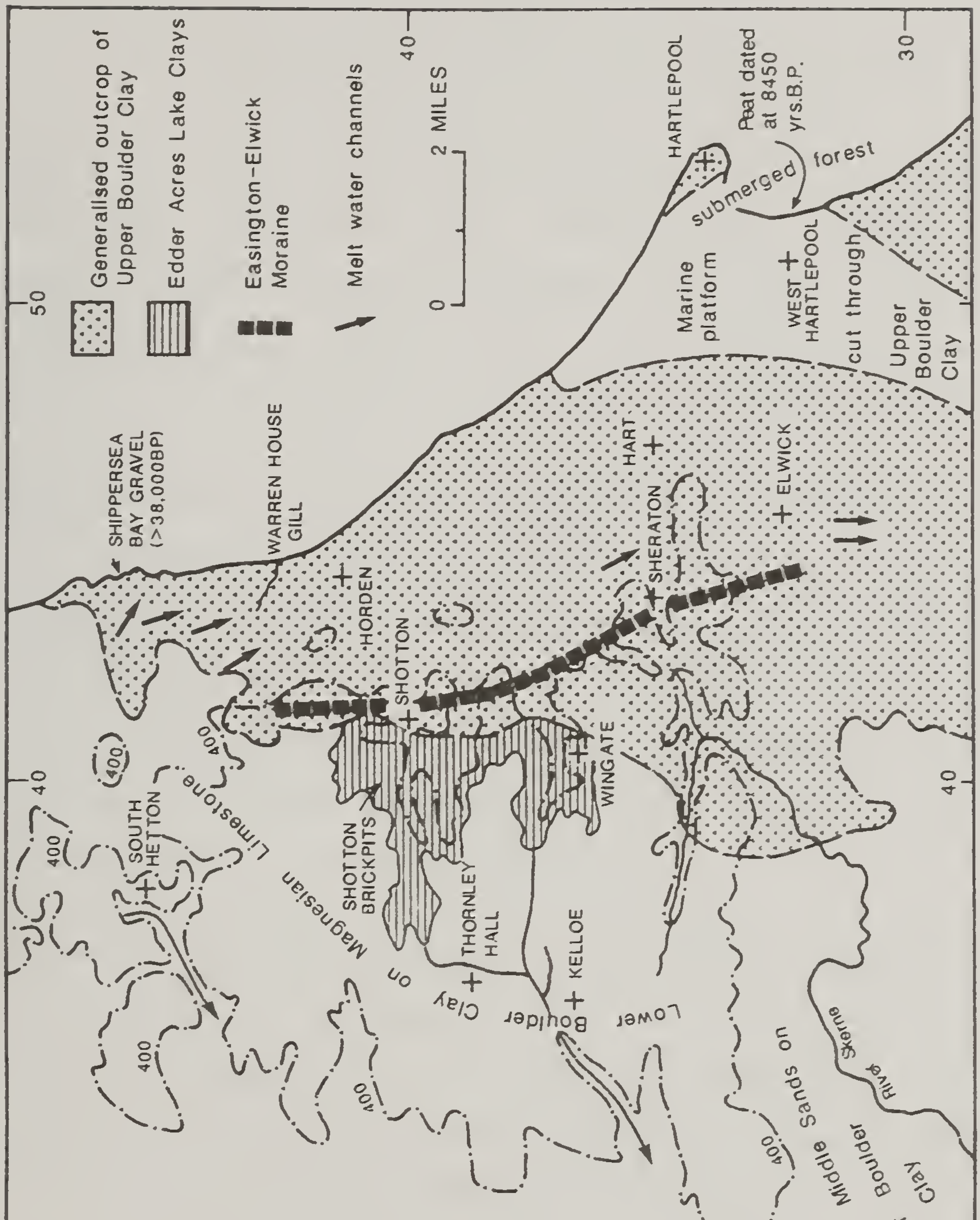
Generalised Section to show the inter-relationship of the Major Components of the Drift Deposits of S.E. Durham



(See next page for key)

Components of the Drift Deposits of S.E. Durham

(6) Morainic Drift
(5) Upper Boulder Clay
(4) Sands, silts, clays and gravels
(3) Lower Boulder Clays
(2) Gravel
(1) Scandinavian Drift.



QUATERNARY FEATURES OF S.E. DURHAM

After D.B.Smith 1965

PARAMOUDRA CLUB BULLETIN

No. 15
May 1967 (for 1966)   Editor: G.P. Larwood

REFLECTIONS ON THE THICKNESSES OF SEDIMENTARY FORMATIONS

Presidential Address, 25th Sept., 1965.

by J.M. Hancock, M.A., Ph.D., F.G.S.

There is a need for more quantitative work in stratigraphy. Note how often a vague term like "shallow water" is used. The one measurement which is usually recorded is thickness, and remarkably little use has been made of this. The example quoted in this manner should be considered with certain principles in mind:

i) Sedimentation is absolutely dependent on subsidence (Barrell 1917); ii) Sedimentation is rarely continous; even thick and rapidly deposited sections contain numerous breaks (Barrell 1917); iii) In detrital sediments the rate of deposition is more than directly proportional to the median grain diameter; iv) However thick sediments may be, the thickness alone tells us nothing of the depth of water at the time of deposition.

It may be possible to argue; one Stage in a System represents about 5 x 106 years; the Stage is divided into 5 Zones so each Zone took about 106 years to be laid down. But one cannot carry such an argument much further. A section containing a single Zone might be divided into 100 approximately equal beds, but the time to deposit a single bed is not 1/100th of the whole Zone, vis. 10,000 years: most of that million years is not represented by any sediments at all, but contained within the bedding planes. The time of deposition of a single bed will be much less than 10,000 years.

<u>Examples</u>

1. Hudson (1964) has shown that pre-Tertiary sediments do not show significant variations in the thickness accumulated per unit time in each period. Deposition appears to be more rapid during the Tertiary because, "The individual thickness measurements, which are summed to produce the cumulative curve of thickness, are made over much shorter time intervals in the Cainozoic than in the Palaeozoic. Since very rapid sedimentation seldom persists for long in any one place this leads to greater observed cumulative thickness in the Cainozoic" (Hudson 1964, p.39).

2. Lower Lincolnshire Limestone (e.g. Ketton Quarry (SK 972057) the lithology is variable in detail but above the basal Collyweston Beds all facies contain ooliths (Taylor 1963, pp.48-49). In a total thickness of about 9*m. there are about 21 distinct bedding planes, every one of which probably represents a break in sedimentation; the tops of some beds are burrowed. The thinnest beds are a few cms. thick, the thickest more than a metre. At least six of them show a rhythmic deposition from sparsely oolitic at the base to densely oolitic at the top (Sylvester-Bradley <u>in litt</u>.).

At the present day ooliths form mostly in water less than 2m deep. Even over the small thickness layer of the Lower Lincolnshire Limestone, subsidence simultaneous with deposition was necesssary. The rhythms and repeated breaks in sedimentation suggest that this subsidence was in jerks.

3. <u>The disappearance of the Hibernian Greensands south-west of Belfast</u>. Around Groganstown, within a distance of 600m, the Hiberian Greensands (22m approx.), 14m of Lias and Rhaetic and an unkown thickness of Keuper, disappear so that in the west the White Limestone

(chalk) rests directly on Keuper. None of the formations which disappear show any sign of being close to its original feather-edge of deposition. Their absence now must be due to Senonian upfaulting to the west and erosion. Sure enough, pebbles of early Hiberian Greensand are found a metre or less beneath the White Limestone in east Antrim, and derived Cenomanian fossils are found occasionally (Hancock 1961).

4. <u>The Cenomanian of south-east Devon</u>. Contemporaneous axes of uplift have affected the thickness and facies of the Cenomanian, and to some degree the Lower Turonian (see figures in Smith 1957, figs. 4b and 8 in Smith 1961, and fig. 4 in Smith 1965).

5. <u>Tidal Sand Waves in Surrey and Saxony</u>. The Folkestone Sands in Surrey embrace about one and a third Zones (Casey 1961) which is about 1/6th of a Stage, or about 106 years. The maximum thickness is 76m and this is composed of sets of cross-strata, each set being up to 5m thick (Allen & Narayan 1964), there being perhaps 25 sets in the whole formation. The Lamarcki Pläner is one Zone of the Quadersandstein in Saxony, about 1/3rd of a Stage (Middle Turonian), say 2 x 106 years, and is 180m thick (Seifert 1955), and single sets are up to 20m thick (H.Prescher <u>in litt</u>.).

The rate of accumulation of this facies in the two areas is about the same - 75 to 90m per million years, but the rate of accumulation is not the same as the rate of deposition. The cross beds in each set have been deposited rapidly; possibly each lamina represents a surge at each high tide. As with the Lower Lincolnshire Limestone, most of the time is not represented by sediment at all. The top sets have often been burrowed by crabs and other animals.

There is still only a limited knowledge of the distribution of sand waves in the sea to-day, but they are known in abundance at depths of more than 91m, as well as all shallower depths of the sea, on tidal flats and in rivers (Stride 1963, pp.180-183). In the Cretaceous examples there is no need to postulate subsidence simultaneous with accumulation, but it seems probable.

6. Relative thickness in geosynclines and shelf areas. There is a general and justifiable belief that in geosynclines there is a thick pile of sediments and that on shelf areas there is only a thin spread. But not all geosynclines are thick: the Tasman geosyncline of eastern Australia is often regarded as a great geosyncline, but the total thickness of the folded Devonian and Carboniferous is less that 3,000m (Knopf 1960). Equally many shelf successions are thicker than this. Lees (1952, p.4) quotes: (a) the unfolded Louisiana-Texas coastal plain, where Tertiary and Mesozoic have a thickness of the order of 9,100m, although many geologists regard this region as an unfolded geosyncline; (b) the Bahamas in the foreland (shelf area) of the thrust mountains of Cuba, where a boring on Andros Island reached 4,400m and was still in Cretaceous; (c) the Arabian foreland zone along the Persian Gulf, where Eocene to Triassic thicknesses are as much as 5,000m, considerably more than the average in the Persian mountain belt; and (d) southern Sind, where a boring at Lakhra drilled to 3,900m found an unexpectedly thick Cretaceous development.

It is instructive to select a single Stage and note its total thickness in various places, e.g. the Cenomanian:

(A) Geosyncline successions:

i) New Zealand - geosynclinal siltstones and greywackes - about 1,250m (Wellman 1959).

ii) Roumania - internal flysch zone of the Eastern Carpathians - about 1,100m (Filipesco 1959).

iii) Spain - in the Vasco-Cantabrian Pyrenees - about 1,000m (Rios 1956, p.88).

iv) Poland - Flysch zone of the Polish Carpathians - the same order of thickness (Ksiazkiewicz 1959, p.182).

These are the greatest Cenomanian geosynclinal thicknesses I have been able to find.

(B) Shelf Succession:

i) England (a) Devon coast, Cenomanian Limestone - 0.75m
(b) Wilmington Sands - 11m
(c) Portsdown boring, Lower Chalk - 103.6m.

ii) North Peru - Cajamarca, mostly limestones and marly limestones - 560m (Benavides-Cáceres 1956).

iii) Tunisia - Djebel Hameima, shales and thin marls - 1,100m (Dubourdieu 1956, p.299).

Rates of sedimentation at the present day

1. Holland, tidal flats of the Wadden Sea: each high tide brings in a little mud so that 1 or 2 mm is built up in a year (van Straaten 1954, p.8). But every year or so a single storm will bring in sand from the North Sea, and 1 or 2 mm of this will be deposited in a couple of hours.

2. Gulf of Paria, west of Trinidad: 6-24 cm per century is the average rate of deposition since the end of the Pleistocene. On the Guiana delta platform the average is only 10 cm per century (Van Andel & Postma 1954, p.141). In the shelf area north of Trinidad clay deposition has been 8.3 to 15.9 cm per century since the end of the Pleistocene (Kildewijn, p.106).

3. Mississippi Delta and neighbouring areas:
a) The delta margin itself:
i) The delta front platform - 1.3 to 2.6 cm per year (Shepard 1960, p.76).

ii) Pro-delta slope - Pass a Loutre, South Pass and Southwest Pass, about 30 cm per year; Main Pass about 13 cm per year. When compacted these sediments would be about half their present thickness (Shepard 1960, p.76).

iii) Offshore deposits - perhaps 3 cm per year (Scruton 1960, p.90).

b) Lagoonal bays of Texas coast:

i) Laguna Madre, south-west Texas: one hurricane washover can deposit "several feet" of sediment, but average over the last 5,000 years is about 12 cm per century (Rusnak 1960, p.194).

ii) Central Texas coast: largely silt, clay and shell fragments; 5,000 to 8,000 years ago, approx. 135 cm per century, around 3,000 years ago only 10 cm per century (Shepard and Moore 1960, p.142).

c) Gulf of Mexico: during the whole of the Holocene, 30 cm to more than 305 cm, but largely in the range 50-200 cm (Phleger 1960, p.292-3).

d) Stable parts of the coastal zone averaged over the whole of the Neogene: Texas and west Louisiana, 0.8 cm per century; Rio Grande area, 1 cm per century; Mississippi delta, 1.6 cm per century (Van Andel 1960, p.53).

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GEOLOGICAL SOCIETY OF NORFOLK

BULLETIN

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AN ASSESSMENT OF THE GLACIAL DEPOSITS OF NORTH-EAST NORFOLK

Presidential Address, Dec. 1967

by

C.E. Ranson, B.Sc.

1. Introduction

This assessment is concerned mainly with the glacial deposits associated with the Cromer Till, the Boulder Clay, the Contorted Drift (sensu Reid, 1882) and the Chalky Boulder Clay or Marly Drift of other authors, and my remarks will refer to them unless I state otherwise. The Hunstanton Till is not considered here. The most satisfactory published stratigraphy for the area is that of Reid (1882, p.2), on which the following table is based.

Table 1

		maximum thickness
8 Boulder Gravel		20m
7 Gravel and Sand		25m
6 Boulder Clay, Stony Loam and Chalky Boulder Clay		22m
5 Sands		18m
4 2nd Till	)	5m
3 Intermediate Beds	) Cromer Till	3m
2 1st Till	)	4m
1 Arctic Freshwater Bed		3m

This is a composite stratigraphy but, except for the Arctic Freshwater Bed, it may be seen in the cliffs between Overstrand and Cromer. For these and other localities mentioned in the text, see Fig. 1. Elsewhere one or more members are usually missing.

The term 'till' is used as a synonym for boulder clay.

I wish to acknowledge the benefit I have received from the many discussions I have had with Dr. Banham over the past seven years: however, I bear full responsibility for all the views expressed here. I also wish to acknowledge the receipt of field-work grants from the Nature Conservancy which have made the preparation of this Address possible.

2. The Regional Setting

The glacial deposits of East Anglia were laid down during a major glacial period when ice came into the region from the west and north. This ice was near to its south-eastern limit. Some of its advances were more active than others in the region. In front of the ice-sheets, spreads of outwash deposits were laid down.

In general terms, the south-eastern limits of each ice advance in East Anglia are marked by a till of more or less uniform thickness overlying older rocks with very few signs of major disturbance at or near the junction. Associated outwash deposits are also fairly uniform and moderately well sorted. Examples of this are the members of the Cromer Till of the Norfolk coast where the cliff sections at Happisburgh, Mundesley and Overstrand show excellent exposures.

It seems that in the extreme north of Norfolk more active ice of a penecontemporaneous or later advance was able to disrupt the Cromer Till and the Sands and it incorporated these within its own load to form the Contorted Drift. This general statement will be elaborated in Section 4, after the presentation of a selection of the more important phenomena seen in north-east Norfolk.

3. Glacial phenomena and their occurrence in north-east Norfolk

The phenomena associated with this period may be grouped under four headings: those of erosion, glacial tectonics, deposition and frozen ground.

A. Erosional phenomena

(i) The surface of pre-glacial deposits now immediately overlain by till have never been shown to have weathered horizons or soils associated with them, though the Arctic Freshwater Bed of Reid is generally thought to be immediately pre-glacial. It is preserved

only in small patches which may be the sites of original lakes and marshes, or the remnants of a more widespread deposit (West and Wilson, 1966).

(ii) The surface of tills and outwash deposits likewise have not been shown to have preserved weathered horizons or soils (Reid, 1882, p.59). This may indicate that there was no weathered horizon at any stage, or that the weathered horizon was eroded before the next deposit was laid down.

(iii) Coherent masses and comminuted fragments of pre-glacial deposits have been recognised within the glacial sediments: the Chalk, the Crags and the Forest Bed being the ususal sources. Examples of these masses may be seen in the cliffs between East Runton and Sheringham.

(iv) Gouges which have been cut into pre-glacial deposits are now filled with till. Such a gouge exists for 300m east of the stream in the cliffs at Beeston (173434), where till lies immediately on top of chalk. (All Grid References are in the 100 km square TG).

B. <u>Tectonic phenomena</u>

(i) The tills show small-scale flat folds amost everywhere. Examples may be seen in the cliffs at Bacton (336347), West Runton (180433), Weybourne (110438), (Banham, 1965).

(ii) The whole glacial sequence and, sometimes, parts of the pre-glacial sequence, in the northern part of Norfolk have been affected by late folding to give open folds, near isoclinal folds, overfolds and thrusts with associated minor folding. These types of deformation may be seen at Paston (330352), Mundesley (301378), Overstrand (240405) and Sidestrand (257404) respectively.

Both of these types of folding are directional, and can be related to ice movement in the area (Banham, 1966).

C. <u>Depositional phenomena</u>

(i) Tills: there are four lithologically distinct tills in north-east Norfolk.

(a) A dark grey sandy till with a few stones and frequent shell fragments. This is Reid's First Till, and may be seen at the base of the glacial succession in the cliffs for one mile north-west of Overstrand village, and in the same position in Happisburgh cliffs.

(b) A grey to brown chalky till with few stones but many small chalk fragments. This is Reid's Second Till, and may be seen in its proper stratigraphical position at Overstrand, and immediately on top of the Cromer Forest Bed Series at Mundesley.

(c) A brown sandy till with few stones, but many sandy and pebbly inclusions which are often shelly. This is Reid's Boulder Clay and Stony Loam: it becomes more chalky north-west of Overstrand. Between Paston and Trimingham, this is the upper of the two tills seen in the cliff section. At Overstrand, it is the uppermost of the three tills; and at West Runton it makes up the bulk of the till in the cliffs.

(d) A pale, very chalky till with sand and stone is prominent to the south and west of Sheringham. Reid equates this till with his Boulder Clay and the Great Chalky Boulder Clay of central Norfolk and Suffolk (1882, pp.116-117). This is also the Marly Drift of various authors (see Straw, 1965). It is best seen in the Town Pit, Weybourne (113431), and in the cliffs at Weybourne Hope (113438).

Where the Boulder Clay (c) or the Chalky Boulder Clay (d) are contorted by folding which often incorporated earlier glacial deposits, Reid described the glacial sequence as the Contorted Drift. It is clear that he did not intend that this term should be used to define a particular stratigraphical unit.

(ii) Outwash deposits

(a) Those associated with the Cromer Tills

There are two separate deposits which can be shown to be stratigraphically distinct at Overstrand:

silty clays, which are probably of the same age as Reid's Intermediate Beds at Happisburgh; and Reid's unnamed Sands. The latter are buff to grey cross-stratified medium to fine sands, and are called the Mundesley Sands by Solomon (1932). There are excellent exposures at Paston and Mundesley (Ranson, 1967).

No fossil remains of any sort belonging to the glacial period have been found in either of these beds.

(b) <u>Those not associated with the Cromer Tills</u>

There is an essentially gradational sequence of water-lain deposits. The gradation is predominantly horizontal, but vertical gradation can be in some sections.

Everywhere in north-east Norfolk these deposits are intimately involved with or overlie the Boulder Clay or Chalky Boulder Clay.

Three members of this gradational sequence may be described to give an indication of the range.

Firstly, non-sorted gravels with interspersed masses of chalky till (Straw, 1965, p.212). These are commonly seen in extreme north Norfolk; for example, in disused pits at Glandford (053415 and 042410).

Secondly, poorly to moderately well sorted gravels, often coarse, but with well stratified sandy horizons. These are typical of the area east and immediately south of the former type, and the Cannon-Shot Gravels (Straw, 1965, p.211) may be included here. These are the gravels of Briton's Lane, Beeston (169417), Beeston Hill (168434) and the Cromer Ridge.

Thirdly, moderately to well sorted sands with occasional gravels of the area southward of Sidestrand and Roughton.

All these deposits have occasional shelly patches, and there is a general deficiency of silt and clay. The only persistent bed of fine material is the horizon of chalky silt and clay which can be traced from Mundesley to West Runton, and is well seen at Kiln Cliff Steps, Mundesley (303376).

Without doubt, these deposits were laid down near to the ice front. Many of the flints in the gravels are freshly broken and

have not travelled far in the glacio-fluvial environment.

Some of the outwash deposits have been ascribed to constructional forms such as eskers, crevasse-fillings, kames and kame terraces (West, 1957a). I do not wish to comment on this aspect of the deposits here.

This is, perhaps, an appropriate place to mention the firm, compact silty deposits found at the surface over much of the Cromer Ridge: this could well be loess. Exposures may be seen on the Roughton - Cromer road at Compit Hills (219406).

D. Frozen ground phenomena

(i) Ice-wedge casts. These were first recorded in north-east Norfolk by West & Donner (1958) in the Cromer Forest Bed series. Since then West and others have noted them in all the water-lain deposits of the glacial sequence except the Intermediate Beds. These casts show that even while the ice-sheets were melting the area was experiencing a very cold climate. No patterned ground phenomena or cryoturbation structures have been recorded from within the glacial deposits, though the top metre or so of most exposures show such structures: these are probably of relatively recent origin.

(ii) The top few metres of the Chalk is often disturbed in one of two ways: it is either fractured by shear planes into blocks a few centimetres across (Banham & Ranson, 1965) or else it has lost its rock-like character and has become what engineers call "putty" or "puggy" chalk. The latter phenomenon is probably related to freeze-thaw processes.

Discussion

It is well known that the literature concerned with the glacial deposits of north-east Norfolk gives a very confused account of their stratigraphy. The present state of knowledge is based on two major publications: Reid's Memoir of 1882 and Solomon's paper of 1932. Reid was mainly concerned with making a map of the Cromer area and drawing a diagram of the distribution of beds in the cliff exposures, and he worked mainly on the general lithological characters of the different beds (one inch Geological Map, Old Series, Sheet 68E). All the beds he described can be seen today in the same relationship to each

other. Solomon made the first serious attempt to describe the petrology and mineralogy of the deposits, and went on to base his stratigraphy on variations in heavy mineral content. It would seem that he did not have the opportunity to map the cliffs at different stages of erosion, for it is not possible to use his stratigraphy at the present day. However, Solomon's stratigraphy is used in the Institute of Geological Sciences' current edition of the Regional Handbook (Chatwin, 1961).

Later papers by Baden-Powell (1948) and West & Donner (1956) established stratigraphies covering Eastern England for the whole of the glacial period. West and Donner's stratigraphy is now generally accepted by most workers. However, both papers point out that the detailed stratigraphy of north-east Norfolk is obscure, and West (1961, pp.365-371) illustrates clearly the nature of the difficulties. While these remain, it will not be possible to put north-east Norfolk into the regional framework.

There is now some urgency in obtaining agreement in north-east Norfolk. Coastal defence works have already reduced the value of several miles of cliff sections, and the next ten years could see the complete disappearance of much of the critical evidence. It may well be that by resolving these local difficulties, new light may be thrown upon other glacial sequences and a contribution might be made to the general stratigraphy of eastern England.

It is the purpose of this paper to put the earlier literature into perspective and to suggest a basis for an agreed solution to the problem by drawing primarily upon Reid's published maps, sections and descriptions, and the writer's observations made during the course of field work in the area with Dr. Banham during the past seven years.

We have found that a satisfactory way to begin work on the coastal sections is to become thoroughly acquainted with the lithologies present. By spending two years working on the Bacton-Trimmingham cliffs we were able to extend our mapping to the more complex Sidestrand - Cromer cliffs where, with one minor exception, we were able to find Reid's complete succession. More recently, we have been able to attempt the resolution of the grossly disturbed Contorted Drift between East Runton and Sheringham by the identification of the pockets and rafts of many of the lithologies seen to the south-east.

We would hope that no-one would wish to disagree with Reid's lithological stratigraphy as seen at Overstrand and Mundesley. If agreement can be obtained on this part of the succession the problem of the Contorted Drift, the Marly Drift and the outwash desposits should be easier to define, and, perhaps, solve. However, this should be treated as a local problem: no attempt should be made to impose accepted East Anglian, British or European glacial stratigraphies on these deposits until an agreement on the local relationship between each bed is established, or, at least, thoroughly sought after.

Clement Reid (1882, p.89), made it quite clear that the Boulder Clay (Stony Loam) of Mundesley and Overstrand and all the underlying deposits have been incorporated in and contribute to the Contorted Drift, which is best developed from Trimingham north-westwards. The Boulder Clay fraction has an increasing chalk content in the same direction, and beyond Sheringham, becomes the Chalky Boulder Clay.

Most later authors (Woodward, 1884; Solomon, 1932, Baden-Powell, 1948; and West, 1961) have acquiesced in this interpretation; but some have pointed out that the evidence is indecisive. They agree that the Contorted Drift and the Chalky Boulder Clay Drift were deposited by the same ice-sheet - probably that now termed the Lowestoft Advance of the Lowestoft Glaciation (West & Donner, 1956). See Table 2.

However, Solomon (1932), Baden-Powell & Moir (1942) and West (1957) have claimed that outwash deposits found near these two tills are of two distinct types and can be related on mineralogical, petrological or gemorphological grounds to different glaciations. The outwash of the Cromer Ridge and the area to the south-east is held to belong to the Lowestoft Glaciation; and that of the Blakeney - Briston - Sheringham - triangle to belong to a later, probably Gipping glaciation, which is not represented by a till in this area.

Straw (1965), after considering the field relations of the two tills, Solomon's mineralogical and petrological evidence and the erosional features exhibited by the outwash deposits, went further. He agreed with Solomon, Baden-Powell & Moir, and West that the outwash deposits are related to two separate glaciations, but claimed that those of the Blakeney - Briston - Sheringham triangle were derived from the Chalk Boulder Clay (Marly Drift) and so concluded that there are tills and outwash

TABLE 2

Stratigraphical relations of the well-defined lithological units of the Upper Pleistocene sequence

Pleistocene Stages	East Anglia (after West)	North-East Norfolk (after West)	North-east Norfolk (after Straw)
Last (Hunstanton) Glaciation	Hunstanton Till and Outwash Deposits	Hunstanton Till and Outwash Deposits	Hunstanton Drift
Ipswichian Interglacial	Bobbitshole Deposits	Erosion Morston Raised Beach	Erosion Morston Raised Beach
Gipping Glaciation	Gipping Till and Outwash	Blakeney - Briston - Sheringham Gravels	Blakeney - Briston - Sheringham Gravels Marly Drift
Hoxnian Interglacial	Hoxne and Nar Valley Deposits	Erosion	Erosion
Lowestoft Glaciation Drift	Lowestoft Till, Corton Sands Cromer Till	Ridge Gravels, Marly Drift, North Sea Drift, Cromer Till, Arctic Fresh-water Bed	Ridge Gravels, North Sea Drift
Cromerian Interglacial		Leda myalis Bed, Forest Bed, Upper Fresh-water Bed	

of two glaciations in this part of Norfolk. He accords Marly Drift and the associated gravels to the Gipping Glaciation.

I would suggest that the field and laboratory evidence available to past and present authors is insufficient for the establishment of any stratigraphy which accords these deposits to two or more glaciations. The types of evidence which would be acceptable are not known to be available in north-east Norfolk. For example, a boulder clay seen to be separating two interglacial deposits; an interglacial sequence seen to be separating two boulder clays; or absolute datings of two different boulder clays indicating an interval co-incident with a known interglacial stage. In fact such evidence is not known anywhere in East Anglia. The interglacial deposits of Hoxne (West, 1956), Bobbitshole (West, 1957) lie at or near the present surface. The botanical evidence shows that they do belong to different interglacial stages, but the geological evidence is not sufficient to conclude that their formation was separated by the passage of an ice sheet and the deposition of boulder clay.

One of the chief characteristics of the tills and their outwash deposits is their variable lithology, petrology and mineralogy. This variability has been demonstrated by Solomon (1932, pp.257-264), and Baden-Powell & Moir (1942, pp.214-215), and discussed by many authors. In the absence of evidence to the contrary, it is unwise to do more than note the variability: in this small area, at least, stratigraphies should not be based on it. The writer has made a number of pebble analyses of the outwash gravels over the whole of north-east Norfolk, including Straw's Marly Drift outwash, of the Blakeney - Briston - Sheringham triangle, the Cromer Ridge gravels and those to the south of the Ridge. These three groups show no consistent differences when pebble petrologies in the 8 to 32 mm intermediate diameter range are compared, though whole pebble samples show real differences. The significance of these analyses is not immediately apparent, but current work might help to interpret them.

It is often said that the Cromer Ridge gravels are rich in erratics compared with other outwash deposits, and the Briton's Lane pit is quoted as a particuarly good site for erratics (Baden-Powell & Moir, 1942, p.214; West, 1961, pp.371, 374). It would be interesting to discover what it is that gives this impression. Is it a function of grading by the pit operators? Is it true only of the large boulders in the gravel? Is this part of the Ridge gravels fortuitously rich in erratics? These questions can be answered by statistical sampling and analysis.

So may many of the problems related to the internal variability of the glacial sequence. But whatever results do come from statistical analysis in the future, they must be consistent with the geological phenomena seen in the field.

These phenomena already give us a useful picture of the environment and the mode of deposition of these sediments. At the onset of active glaciation an ice sheet moved over the permafrost surface of the Arctic Freshwater Bed and the upper part of the Cromer Forest Bed series (West & Donner, 1956; 1958). This ice sheet, which left behind the First Till disturbed the top two to three metres of the underlying beds in places, and may have removed some as well. The First Till is not present everywhere now: its most notable absence is in the Bacton - Trimingham section. The deposits immediately on top of this till are cross-stratified sands and silts with some clay seams: these are the Intermediate Beds. It is probable that they were laid down in a broad expanse of slow moving water coming from a melting ice sheet. They are probably more or less contemporaneous with the underlying till, for they seem to have the same distribution. No fossils of contemporary life are known from these beds.

There is no evidence of any major interval of time before a second sheet of boulder clay was deposited over much of the same area as the first: this is the Second Till. It is seen lying either on the Intermediate Beds (at Happisburgh and Overstrand) or directly on the Cromer Forest Bed Series (at Mundesley). At Mundesley, the top part of the Cromer Forest Bed Series is disturbed by drag folds. These may have been produced by the First Till, now eroded away with the Intermediate Beds, or as seems more likely in the absence of any evidence of substantial erosion, they were produced by movement of the Second Till during or after emplacement. They indicate movement from north-west. Where the Second Till overlies Intermediate Beds, there is no evidence of major disturbance.

Probably soon after deposition, fluvial melt water flowed over the surface of this Second Till (Ranson, 1967). It eroded some of the till and left a thin pebble bed on top of the till, but then it deposited at least 18m of cross-stratified sands in a more or less continuous sequence. Ice-wedge casts have been recorded in certain silty horizons indicating that the climate was still cold. No evidence of contemporary life has been found in these sands (Sands of Reid: the Mundesley Sands of Solomon, 1932). How long deposition continued, and what the maximum

thickness of these sediments was cannot be discovered for the top of the Sands is always disturbed for 1-3 metres and it is obvious, especially in the Mundesley sections, that the overlying Boulder Clay has cut off the top of the Sands in an irregular manner. The Sands are compacted but unconsolidated, and they would have been quite unable to survive any prolonged period of erosion. It would seem that the Boulder Clay was deposited soon after the Sands.

The ice which deposited the Boulder Clay came into the Mundesley - Cromer area from a westerly direction (Banham, 1966, p.471). It can be traced around the coast from Bacton to Weybourne. At Mundesley and Overstrand it is a sandy till with some chalky material: further north-west it becomes more and more chalky until west of Sheringham it is often little less than reconstituted chalk. In the same direction, the degree to which older glacial deposits are incorporated in the Boulder Clay becomes greater. At Overstrand there is an intermediate stage with the whole succession caught up in near-isoclinal folds. At West Runton, the older glacial deposits have been dragged out into detached lobes and pockets, or even completely assimilated, with no sharp lithological boundaries visible. This disturbed part of the glacial sequence is the Contorted Drift.

With this internal deformation of the glacial sequence came the detachment of very large rafts of Chalk and Crag (Peake & Hancock, 1961, pp.324-330). These rafts are also incorporated to form part of the Boulder Clay. Where the line between the Boulder Clay and its disturbed form, the Contorted Drift, should be drawn is not clear. The place where the southern-most striking structures are seen at Mundesley (TG 306374) should serve for most purposes, though Reid (1882, p.93) indicates that the Boulder Clay ceases to be a separate bed north-west of Trimingham.

The cause of the large-scale deformation of the Boulder Clay and other beds is far from being understood: field evidence is more or less equally divided between penecontemporaneous and post-depositional deformation.

Above the Boulder Clay and Contorted Drift lie Reid's Shelly Sands and Loams with the associated Boulder Gravels and Sands. These are all water lain when seen in the coastal sections and in

the pits east of Kelling. At Glandford, Briton's Lane, Beeston and elsewhere pits show the gravels intimately mixed with masses of Chalky Boulder Clay, and they sometimes contain only faint signs of water action. In general, the higher land south and east of the Cromer Ridge as far as Norwich and Yarmouth is virtually covered by beds of sand which are as much as 25 metres thick. In the northern part of this area, between the Ridge and Worstead and Hevingham, this sand is almost certainly the product of one sedimentary process. Detailed field work has suggested that melt water from the Ridge district carried the sands and gravels across the area to the south. Fluctuations in the volume and velocity of melt water, and in the course of the main streams can quite satisfactorily account for the lithological variations recorded in the literature and seen in the field. These sands are generally well to moderately sorted, and are conspicuously poor in finer material (Ranson, 1967). Occasional clay and silt horizons are seen, and one bed of chalky clay up to two metres thick has been recorded within the sands at Mundesley, Sidestrand and West Runton, and may well be continous. This thick bed probably indicates that there was a period when this part of Norfolk was covered by a lake or a series of broad distributaries draining the melting ice sheet.

The valley gravels at Bacton (Reid, 1882, p.118) and in central Norfolk are probably deposits of material reworked from this original outwash.

The significance of the shelly content of these sands at certain places is fully discussed in West (1961, pp.368-371), with the preponderance of opinion being in favour of the fauna being derived. This is wholly reasonable if the sands are held to be of glacio-fluvial origin. The shells with no known local provenance could have been derived from masses of other crag deposits to the north of East Anglia which were picked up in the ice sheet and left more or less intact when the ice melted, or were dispersed by melt water. It would be interesting to see the faunas of these sands systematically compared with those of the shelly pockets found within the Contorted Drift (Reid 1882, p.102). From a purely sedimentological point of view, it would seem unlikely that these sands were deposited in a marine environment. There is also evidence of a cold climate at the time of deposition to support this view (Ranson, 1967). However,

it could well be true that the sands and gravels are of marine origin, and that some of their original characters have survived the glacial episode. For example, the Cannon-shot gravels might well have come from earlier shoreline deposits incorporated in the ice-sheet.

Reid did not find any shells in the coarser Boulder Gravels of the Ridge. However, in the recently extended pit at Briton's Lane (169417) shelly patches of sand and gravel have been noted (Baden-Powell & West, 1960, p.76).

There seems to be little doubt that these sands and gravels were deposited at roughly the same time as the Boulder Clay-Marly Drift till. They are always contorted with the till, they are often intimately associated with the till, and there is no sign of weathering or erosion between the till and the sands and gravels. It would seem that the ice which brought these deposits also produced the contortions during late subsidiary movements. The possibility of a further ice advance giving rise to these deposits cannot be ruled out completely, but it did not leave any recognisable till - unless as Straw (1965; 1967) envisages the Marly Drift is considered to be the product of just such an ice sheet.

But before such a possibility can become a probability, significant evidence of an active ice sheet must be found; and if this later ice sheet is to be ascribed to a later glaciation, then the necessary climatic or chronological evidence must be produced. At the moment, there is no such evidence: indeed, there is no evidence of climatic amelioration to the Interglacial conditions anywhere within the glacial sequence of north-west Norfolk. This is the cause of, and may be the solution to, the stratigraphical confusion of this important series of late Pleistocene deposits. So I conclude that, so far, the glacial sequence has not yielded any unequivocal evidence to suggest that it was deposited during more than one glacial stage.

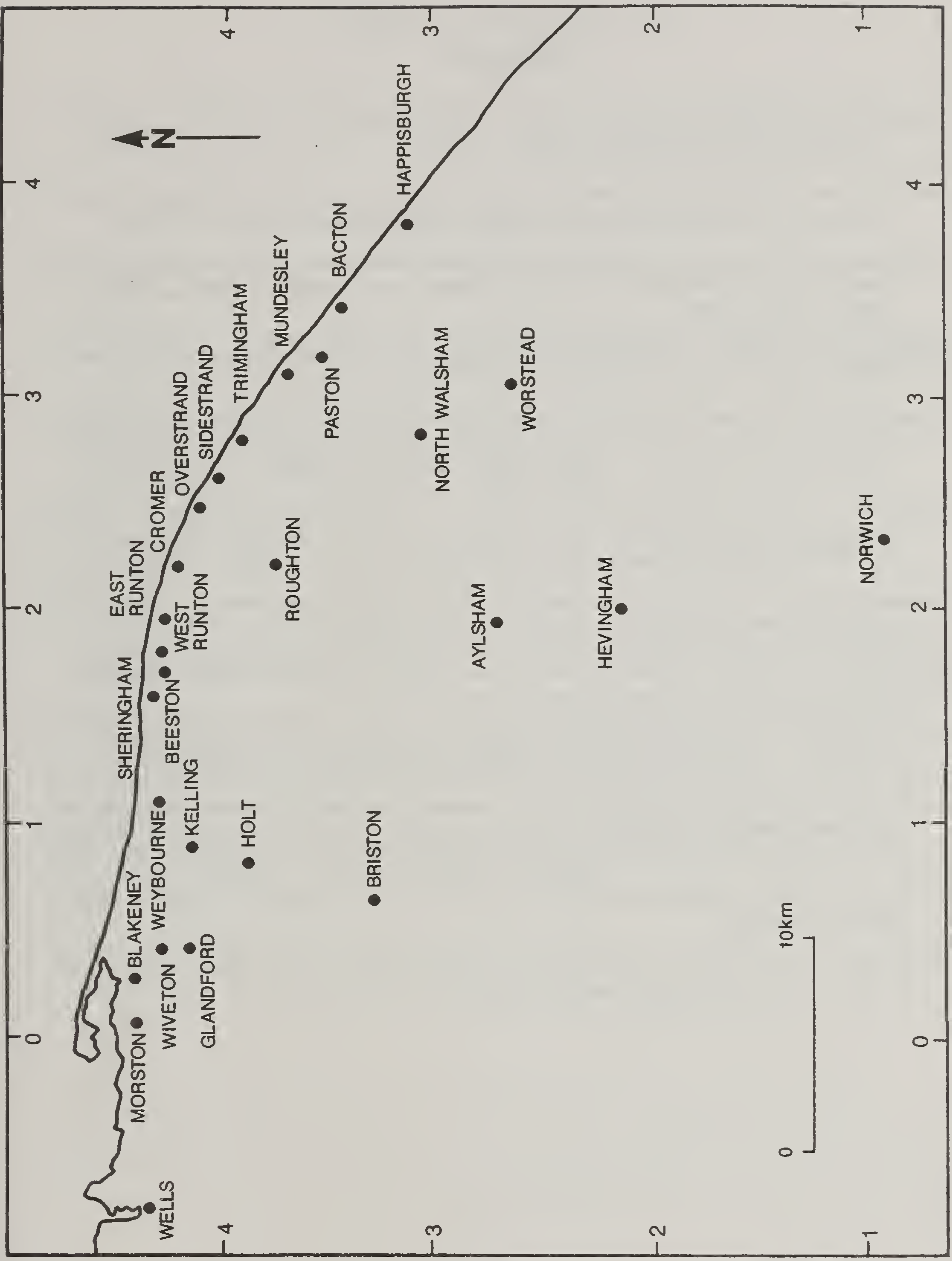

Figure 1. LOCATION MAP
The map is drawn on national grid 10 km base.

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INVESTIGATION INTO THE GEOLOGY OF THE SITE OF THE UNIVERSITY OF EAST ANGLIA

by

A.K. Fowler and M.R. Leeder

The extensive excavations for the foundations of the University of East Anglia and other buildings have given us the opportunity for detailed study of the geology of the Yare valley between Colney and Cringleford. Work on the University site (Grid Reference c.TG 194079) has revealed exposures in the Eaton Chalk division of the zone of Belemnitella mucronata (Peake & Hancock, 1961). This is overlain by a thin but complex deposit of discontinuous sands and poorly sorted gravels lying in the irregularities of the chalk surface.

Between 85′ and 60′ O.D. the solid, well-bedded chalk is overlain by up to 5 ms. of the crumbly or "putty" chalk described briefly by Ranson (Paramoudra Club Bulletin, No.13, p.8). This deposit consists of thinly or poorly bedded chalk, often yellowish towards the surface, containing rounded fragments of solid chalk set in a softer matrix. The isolated fragments of B. mucronata found in this chalk are often pitted and the outer layer of the guard partially destroyed. Smaller fossils such as Cretirhynchia lentiformis Pettit are often intact, but only scattered plates of larger fossils such as Echinocorys are found. The boundary with the normal chalk is broadly transitional.

This re-arrangement of the chalk indicates formation by a process of freeze/thaw in the water-saturated active layer (mollisol) in areas of frozen ground during the Quaternary era. If solifluction took place, this would have aided the process. It may be significant that putty chalk is never developed when the solid chalk is overlain by a thick sequence of Norwich Crag, as seen in other exposures in Norwich at Catton Grove (TG 229109) and Eaton Limeworks (TG 208063).

In one exposure the putty chalk took the form of two ridges 1m in height, adjacent to each other and surrounded by light-coloured coarse-grained sands (Fig. 1). These were apparently continuous for at least 1m along the direction of strike of the ridges, and were surrounded by a thin band of ironstained sand with occasional flints lying parallel to the sides of the ridge.

In considering the origin of these features the work of Butrym et al. (1964) is important. These authors describe pillar involutions of irregular clay dykes and clay bulges into overlying sandy sediments as due to differential loading at the clay/sand interface. This interface may be unstable when unconsolidated sands rest on soft, water-saturated, thixotropic clays. Disturbances or irregularities destroy the equilibrium at the interface and produce the pillar involutions by injection of the clay into the sand (c.f. Butrym et al. p.8, fig. 5). These features so produced are not held to be diagnostic of periglacial conditions as a general rule, for they may be expected in many kinds of sedimentary environments wherever clays and sands are superimposed. However, Butrym et al. conclude that abundance of ground water and a permanently frozen zone beneath the mollisol as found in periglacial areas, provides ideal conditions for such processes to operate.

The almost vertical position of the chalk ridges, the marginal parallel flints, and the presumed contrasts between water-saturated putty chalk and overlying sands, suggest an origin of deformation by loading to give injection of the putty chalk into the sands. The conditions for such a process were probably satisfied during periods of permafrost conditions, or by ice-loading during glaciation. They need not, therefore, be periglacial structures in the strict definition of the term.

The associated gravels, sands, and clays are of variable thickness, being absent in some parts, but generally around 1m and up to 4 ms. in one exposure. They are probably glacially mixed forms of either the Norwich Brickearth (we are indebted to Prof. Funnell for this suggestion), or possibly Norwich Crag. They are probably derived from the plateau to the north of the site, but pebble orientations, which would have indicated possible lines of derivation, were unfortunately not taken. (See Table 1 for comparative pebble analyses.) A deep basin in the chalk surface 70′ above the river contained a well-sorted series of fine gravels, sands and clays. These are being investigated for foraminifera, in an effort to obtain more evidence concerning the origin of the superficial deposits. It is also hoped eventually to investigate the series for pollen.

Table 1

Pebble analyses of the Norwich Crag, the Norwich Brickearth and gravels from the University site for comparison:

Norwich Crag (western facies) Eaton Lime Pit, G.R. TG 208063 Bed 5 185 pebbles					University site G.R. TG 194079 Sample type 10/20 173 pebbles					Norwich Brickearth Lodge Lane, G.R. 217 pebbles				
Grade (mms)	%F	%Q	%QZ	%O	Grade (mms)	%F	%Q	%QZ	%O	Grade	%F	%Q	%QZ	%O
+35	100	0	0	0	+35	0	0	0	0	+35	100	0	0	0
35-25	100	0	0	0	35-25	83	17	0	0	35-25	75	0	0	25
25-15	90	0	10	0	25-15	66	14	17	3	25-15	78	4	6	12
15-5	91	3	6	0	15-5	47	23	23	7	15-5	67	16	11	6
% Total	95	1	4	0	%Total	66	18	13	3	%Total	80	5	4	11

(F-Flint; Q-Quartz; QZ-Quartzite; O-Others - igneous, metamorphic, seds., chert, etc)

An extensive area of putty chalk with an admixture of broken flints and a high sand content (possibly a solifluction deposit), has been revealed on the lower component of the slope. The relationship of this with the upper deposits was seen to be one of intercalation rather than mixing.

A trench for a sewerage pipe gave a longitudinal section of the Yare floodplain from Cringleford to Colney, in places revealing at least 15′ of valley gravels overlain by discontinuous muds and peats and in other places cutting through the chalk. Th existence of 15′ of gravels implies that at some stage the river has excavated to a lower level at least 15′ below the present valley floor. The trench did not reveal the relationship between the valley deposits and the ?solifluction deposit.

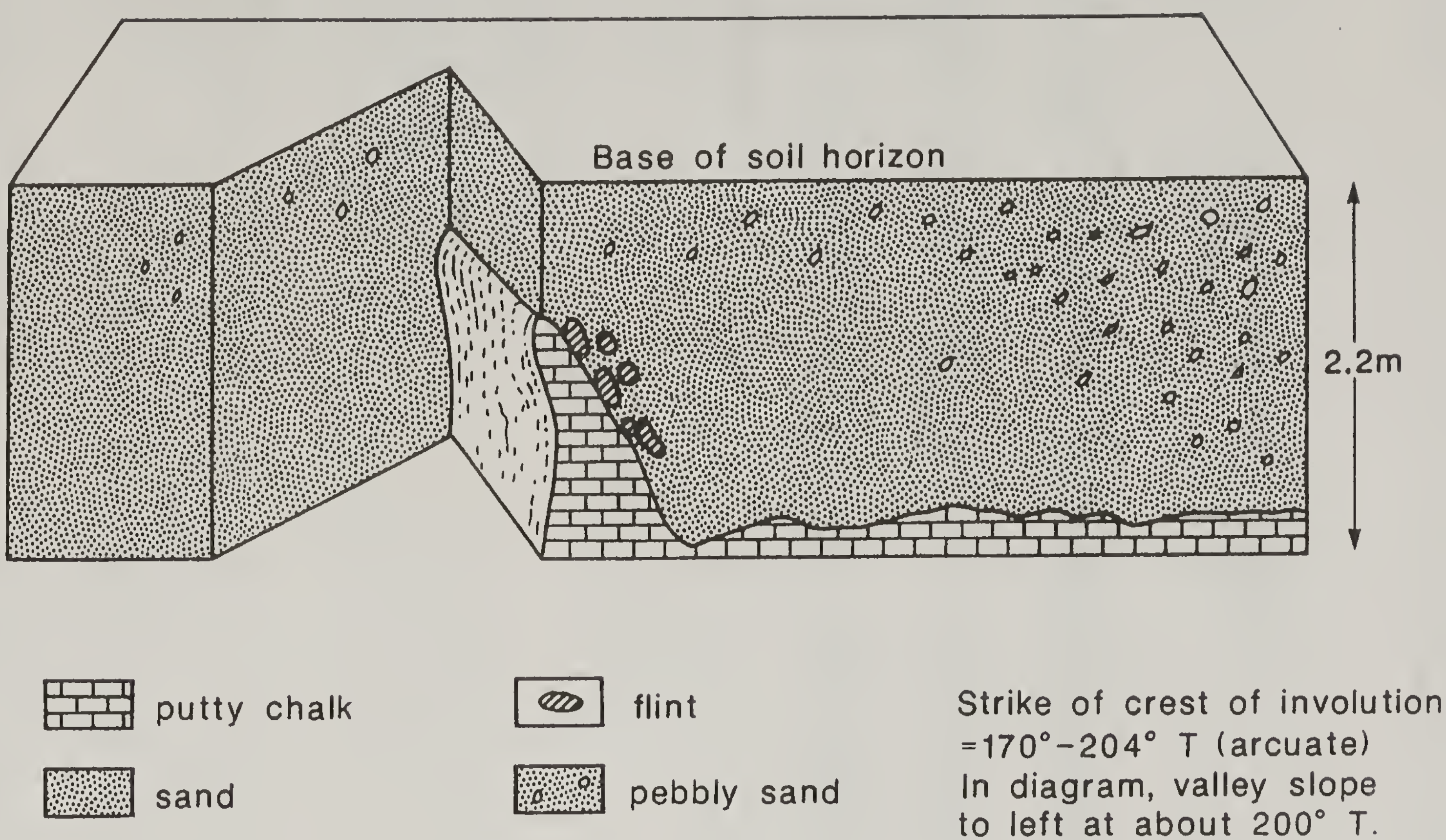

Fig.1 Section from foundation excavations showing chalk pillar involutions which have been intruded into overlying sands. Note the lateral persistence of the large involution and the vertical position of the surrounding flint pebbles.

Acknowledgements

The authors wish to thank Mr. C.E. Ranson for his encouragement and helpful advice, and Professor B.M. Funnell, Dr. P.H. Banham and Mr. N.B. Peake for their helpful suggestions. Finally, we would like to thank R.G. Carter Ltd., for their co-operation in providing access to their site and plans.

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GEOLOGICAL SOCIETY OF NORFOLK

BULLETIN

No.17 (Paramoudra Club)

August 1969 (for 1968) Editor: C.E. Ranson

Contents

NOTICES AND NOTES

Forthcoming Meetings

Sunday, 24th August: Joint meeting with the Norfolk and Norwich Naturalists' Society to examine coastal Chalk, Crag and Forest Bed exposures. Meet at 10.30 a.m. North Walsham Market Place, or 9.30 a.m. Bell Avenue, Norwich. Leaders: N.B. Peake and P.G. Cambridge.

Saturday, 30th August: Visit to Scolt Head Island or Titchwell to study intertidal deposits of the north Norfolk coast, meeting on the coast at about 10.30 a.m. (depart from Bell Avenue, Norwich, at about 9.30 a.m.). All members wishing to participate must ring Professor Funnell at Norwich 56161, Extn. 338 by Thursday, 28th August, for details.

Thursday, 25th September: Demonstration meeting, "Preparing fossils and making a collection" demonstrating palaeontological techniques, to be held at the University of East Anglia. Meet at the Porters Lodge, Wilberforce Road, at 7 p.m. Members are invited to bring problem specimens.

Thursday, 2nd October: E.G.M. at the Norwich Castle Museum at 7.30 p.m. (a notice of which is enclosed with this Bulletin) to adopt the new constitution.

Thursday, 23rd October: Talk, "The Norwich water supply with special reference to recently constructed boreholes" by R.J. Bell, Deputy Water Engineer and Manager, Norwich Corporation Water Department, 7.30 p.m. Norwich Castle Museum.

Thursday, 27th November: Talk, "Margins of modern ice-sheets and their relevance to the glacial geology of Norfolk" by Dr. G.S. Boulton, 7.30 p.m. Norwich Castle Museum.

Notes

Meetings of the Quaternary Research Association and of the Colloque pour l'étude du Neogene Nordique will be held at the University of East Anglia April 3rd - 6th, and March 31st - April 6th, 1970 respectively. Our Hon. President (Prof. B.M. Funnell) has been nominated President of the Norfolk Research Committee for 1969-70, and will be giving a presidential address on "Research into Norfolk - problems and prospects" at the Norwich Castle Museum, 2.30 p.m. Saturday March 21st, 1970.

Forthcoming contributions to this Bulletin include: A preliminary account of two further research boreholes at Stradbroke and Hoxne; notes concerning some rhynchonellid and terebratellid brachiopods from the zone of *Belemnitella mucronata* in Norfolk; interglacial beds at Beetley, Norfolk; observations on iron mineral geodes in Norfolk; and a list of members.

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A PRELIMINARY ACCOUNT OF RESEARCH BOREHOLES AT BECCLES AND GT. YARMOUTH

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The purpose of this note is to present the initial findings of two research boreholes recently drilled in East Anglia. The two holes are the first of a series of borings in Norfolk and Suffolk which are being carried out by the School of Environmental Sciences, University of East Anglia, and the Sub-Department of Quaternary Research, University of Cambridge, with a grant from the Natural Environment Resesearch Council. The project is intended to increase our knowledge of the stratigraphy and palaeontology of the early Pleistocene Crags and enable us to build up an environmental history of the Lower Pleistocene in East Anglia. Some information on water supply problems is also expected to be obtained. The borings in Suffolk should provide information about the relationships between the Norwich Crag and the Red Crag, and about the Coralline Crag and the Plio-Pleistocene boundary. The boreholes at Ludham described by Funnell (1961) and West (1962) provided a great deal of information about the foraminifera, pollen, molluscs (Norton 1967) and dinoflagellates (Wall & Dale 1968), and about the climatic history of the Lower Pleistocene in Norfolk, and demonstrated the potential of an extended borehole programme.

<u>Borehole UEA 1</u>. <u>Beccles Water Works, South Road, Beccles</u>
(TM 418894)

Drilled in January and February, 1969. The altitude of the ground level was surveyed to a new bench mark on the water tower, for which Ordnance Survey has yet to calculate the precise height above O.D. The surface is approximately +100′ O.D.

The borehole was made close to the site of a boring made in 1871 (Woodward 1882, p.156 - No. 2 well) which had given the following succession:

O.D. +107′	
1′ - 11′	soil and boulder clay
11′ - 25′	sand and loamy sand
25′ - 28′	pebbly sand
28′ - 35′	sand
25′ - 40′	sand and large gravel
40′ - 55′	gravel
55′ - 60′	sand

60′ - 62′	gravel (iron bound)
62′ - 91′	sand with shells
91 - 110′	silty clay
110′ - 134′	transition to sand
134′ - 157′	sand with clay lumps
157′	Chalk

Reference to the figure will show that the succession proved in borehole UEA 1 was generally comparable with that in the log of the old No. 2 well, but differed with respect to the silts and clays between 91′ and 110′. In the present borehole the sediments found at that depth were fine sands with occasional clay lenses. The discrepancy between the old record and the present borehole was unfortunate because an argillaceous sequence would have allowed a continuous series of cores to be taken for pollen and palaeomagnetic analysis.

Borehole UEA 2. Lacon's Brewery, Great Yarmouth. (TG 523079)

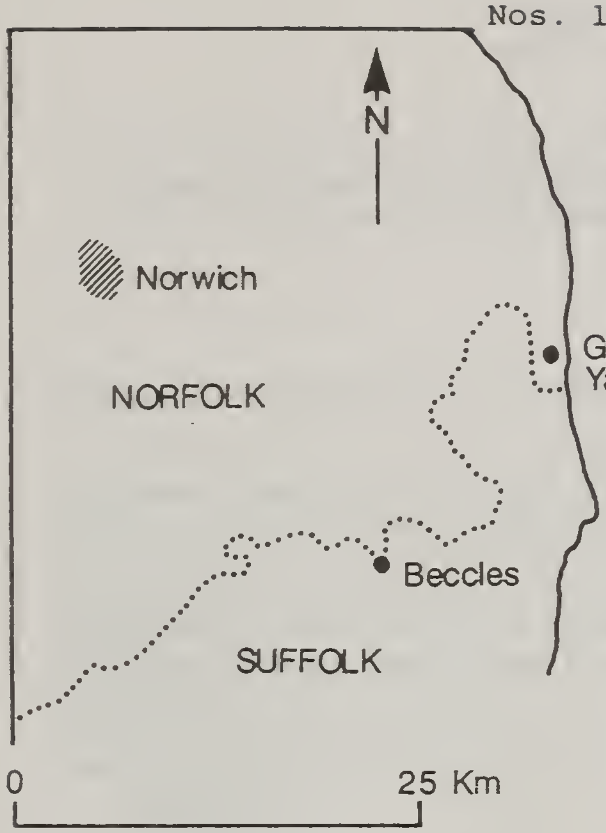
Drilled in February and March 1969. Surface level +20.85′ O.D. As in the case of the previous borehole, the site was chosen near to the position of a former boring to provide some stratigraphical control. A boring for water had been made in the yard of the Brewery in 1840 (Blake 1890, pp.81-2) which, according to the log, proved the following succession:

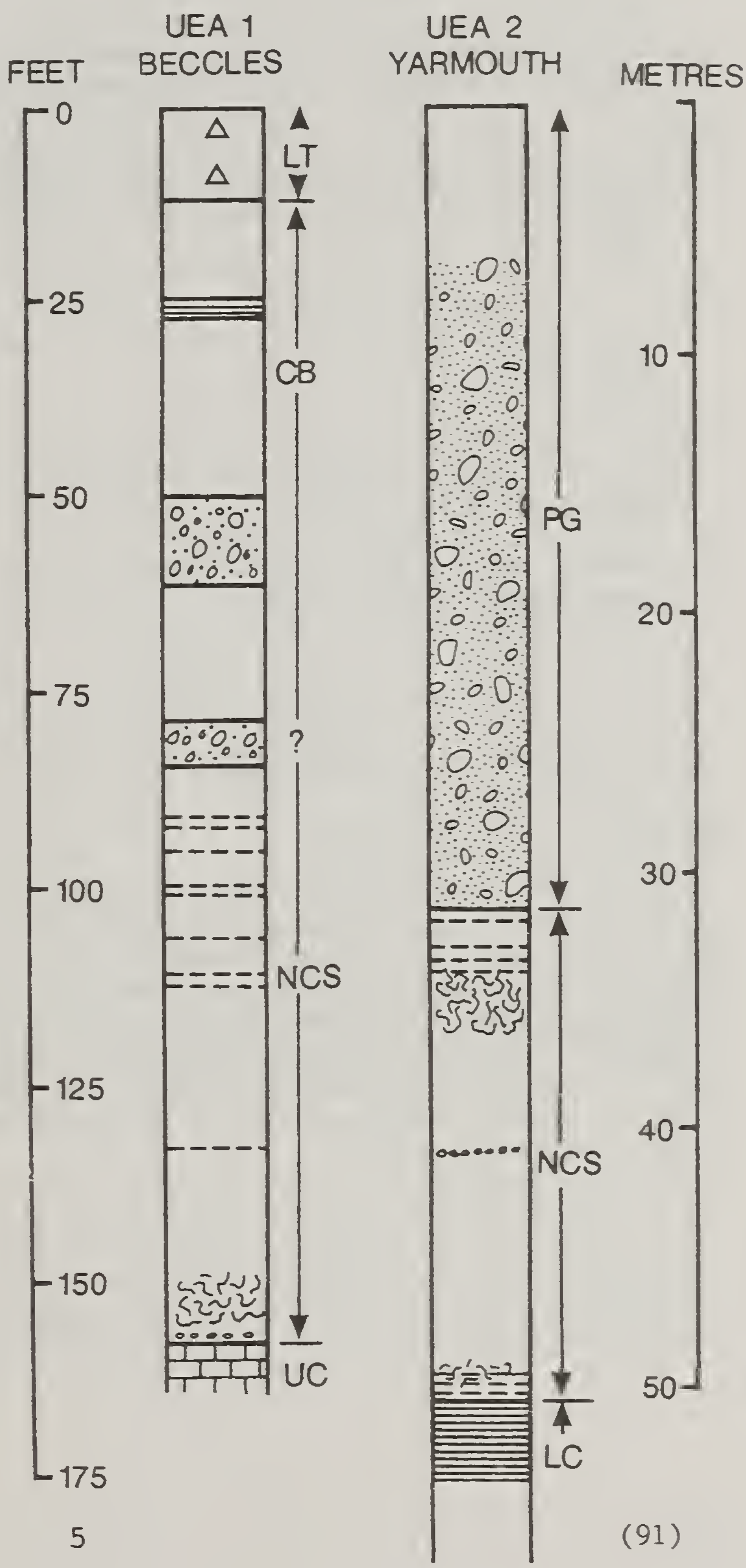
O.D. +20′	
0′ - 50′	sand and shingle
50′ - 58′	coarse sand with shells
58′ - 109′	light grey clay
109′ - 156′	sand with shells
156′ - 166′	clay with shells

underlain by London Clay, Reading Beds and Chalk to a total depth of 597′ below the surface.

The sequence proved by the present boring differed markedly in the upper part from that shown in the old log. Some 103′ of sands and shingle were penetrated before grey Crag sands were reached, whereas the old log indicated light grey clay between 58′ and 109′. Similarly, the old log recorded clay with shells from 156′ to 166′ below the surface, but only 3′ of clay bands in sand were actually found.

SIMPLIFIED LOGS OF THE RESEARCH BOREHOLES AT BECCLES AND GREAT YARMOUTH





KEY

PG Post Glacial

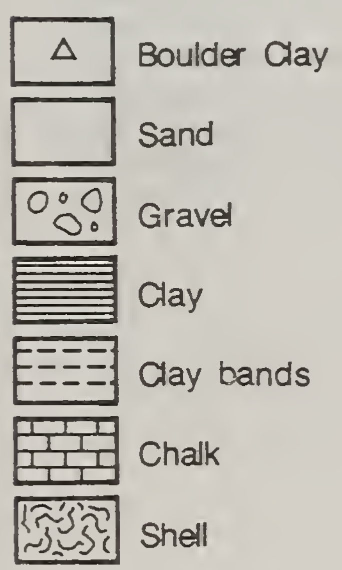
LT Lowestoft Till

CB Corton Beds

NCS Norwich Crag Series

LC London Clay

UC Upper Chalk



Acknowledgements

The generous co-operation of the East Anglian Water Company and Lacon's Brewery is gratefully acknowledged.

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FIELD MEETING TO BRAMERTON, 20TH APRIL, 1969.

Leader: P. Cambridge.

Three members and three visitors attended the meeting to Blake's Pit, Bramerton, Norwich (TG 298061). The Norwich Crag was examined in a small section in a wood. The beds are here highly fossiliferous and noted for the monstrosities of *Littorina*, *Nucella* and *Neptunea*. Specimens were collected and samples taken for later examination. A shelly pocket near the top of the pit yielded a number of specimens of black fossilised wood, another indication of shallow water facies of the Norwich Crag at this point.

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FIELD MEETING TO BLACK DYKE FARM CHALKPIT, AND TO THE SHAFTS AND TUNNELWORKS FOR THE ESSEX WATER ABSTRACTION SCHEME, 8TH JUNE, 1969

Leaders: N. Peake & P. Cambridge

Ten members and friends assembled in the old chalkpit adjacent to Black Dyke Farm (TG 690585), 2 miles west of Hockwold, where a brief account was given of the tectonic history of the region since the beginning of the Cretaceous, with particular reference to the palaeogeography of the Gault and Chalk seas, and to the relations between these two facies and greensands in other parts of Europe. The nature of the chalk sedimentation was described, with its concomitant reworking (bioturbation) by Thalassinidians, annelids and Zoophycus.

The pits shows the top 15′ or so of the Schloenbachia varians Chalk, followed by 2-3′ of the coarse gritty yellowish Totternhoe Stone, (with its basement bed of rolled green-coated chalk pebbles - currently well-shown at the southern end of the pit). This is overlain by a softer greyish-white chalk, with striking curvilinear jointing, of the Holaster subglobosus zone. Thalassinoides (the infilled burrows of a presumed fossil ancestor of the ghost-shrimp which is, itself, never preserved) were well seen in and just below the Totternhoe Stone (where they show up well because their infill differs in colour and/or grain size from the surrounding chalk); other burrows and a probable gastropod-track were also demonstrated. The Totternhoe Stone yielded several brachiopods and one regular echinoid, while frost-cleaved planes in the chalk below yielded numerous compressed examples of Schloenbachia (including the Zonal species) and Inoceramus and one or two good casts of Pecten beaveri and Plicatula sp. In the entrance to the pit was a huge dump of dried Gault ′sludge′ which has been mechanically excavated from the nearby tunnel (see below). Owing to the action of the rotary-blade excavator, only those fossils preserved as or upon phosphatic nodules (such as Inoceramus sulcatus and fragmentary ammonites) and the guards of small belemnites (Neohibolites spp.) were obtained.

The co-leader then gave an account of the post-glacial features of the pit, including the pockets in the chalk ′head′ in which the remains of land-snails and slugs appear in the chalky matrix, and in which he had found a single example of Ena montana - the most northerly record (fossil or recent) for this woodland-loving species. He also described some of the archaeological

sites in the area, along with the significance of the 'treasures' (from Neolithic to Romano-British Age) that have been unearthed from them.

150 yards S.S.E. of this pit, (and on the south side of the cut-off channel) a visit was paid to No.1 shaft for the Essex River Authority and Great Ouse River Authority Joint Scheme for abstracting water from the Fen flood-relief channel. An outline of the scheme was given: it involves a reversal of direction-of-flow in the channel from its point of discharge into the tidal Ouse below Denver Sluice to the primary intake at this shaft, whence the water will travel southwards through the 8'4" diameter tunnel through the impervious and easily-excavated Gault Clay, for 12* miles to Kennet (near Mildenhall); from there subsurface aqueducts and an improved stretch of the Stour and Blackwater will convey water to the Abberton and Hanningfield reservoirs in Essex. A series of vertical shafts are being sunk at roughly one mile intervals to meet the tunnel, and so enable more water to be intercepted from other fenward-flowing rivers.

No.3 shaft by Lakenheath Lode (TL 693811) was next visited. Here the shaft had so far been sunk only a few feet below the water-table, but was surrounded by a circle of refrigerant-pipes sunk to 120' - their exposed portions being thickly coated by ice, glistening in the hot sunshine; once an annulus of water-saturated chalk has been sufficiently frozen (4-6 weeks is normally required) the shaft can be excavated 'dry' at a rate of 10'-15' per day until it reaches 20' or more below the top of the Gault, the shaft then being lined with concrete segments which are grouted in and made water-tight before freezing is discontinued.

The party then proceeded to the other end of the tunnel at Kennet (passing several cottages largely built of Totternhoe Stone, on the way) where the shaft had been sunk to its full depth of 240' (the middle of the Gault lies at a much greater depth here since chalk of the Middle Turonian occupies the ground-surface, and the Gault itself thickens very considerably southwards). A heading had been dug manually here from the base of the shaft (of sufficient size to accommodate the tunnelling-shield, which was soon to be lowered down the shaft), and this material was examined. It proved to be similar to that described next.

Returning northwards, the last shaft visited was that at Worlington. This had been completed and lined to its full depth, and members peered down with awe at the floor 190' below; withdrawal of the refrigerant pipes (by simply pulling them up by

crane) had commenced. The dump of material from the lowest part of the shaft proved to be particularly rewarding. Some of the very large lumps of Gault when split open revealed surfaces covered with ammonites, mainly Euhoplites spp. and Hamites, with Inoceramus concentricus, I. sulcatus, and Trigonia aliformis. Neohibolites (often of unusually large size) was abundant, and a crab (Palaeocorystes cf. stokesi) and an echinoid (Hemiaster sp.) were collected. Most of the fossils occurred as moulds (usually brown-stained) in the clay, and phosphatic nodules were comparatively rare. Some cleaved faces showed a plexus of thalassinid-like burrows (with infills lighter than the surrounding clay), themselves cut by many small burrows, dark grey in colour, of Chondrites.

Finally, on the return, some members stopped to look at the large quarry at Chalk Hill, Barton Mills (TL 712721). From it fossils characteristic of the Melbourn Rock (basal Turonian) were obtained. These included Inoceramus labiatus (the zone fossil), Holaster, Conulus and the huge Lewesiceras. Splendid examples of frost-festooning were noted along the south face of the quarry.

Thanks for permission to view the sites are due to the respective quarry-owners, to Binney & Partners (consultants for the Abstraction Scheme), to Nuttalls Ltd., (the tunnellers), and to Foraky Ltd., (who are sinking the shafts and doing the manually excavated heading at their bases).

BRYOZOA AND THE ORIGIN AND EVOLUTION OF THE CHEILOSTOMATA

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1. Introduction

Bryozoa are among the commonest fossils occurring in marine sediments in the stratigraphical sequence exposed in East Anglia. In particular the rich and well preserved bryozoan faunas of the Chalk and Pleistocene Crags are well known. Localities in the Albian of Norfolk and Cambridgeshire have also yielded some of the earliest known Cheilostomata. The general structure of Bryozoa and their component orders is reviewed and the origin and evolution of cheilostome bryozoans is considered.

2. General Bryozoan Characters

Bryozoa inhabit both freshwater and marine environments. They are small tentacled animals (about 1.00 mm long) which live in association forming colonies of connected individuals.

Each individual, or zooid, has a circle of food-gathering tentacles rising from a fleshy lophophore which surrounds the mouth. The gut is 'U'-shaped and is recurved so that the anus lies close to but outside the ring of tentacles. These structures and other organs together with a musculature are contained in an enveloping body wall. Many forms of Bryozoa, both extinct and living, secreted an external calcareous skeleton. The adjacent secreted skeletons of individuals (zooecia) are commonly preserved fossil and it is these colony skeletons (zooaria) which are so often well preserved in the Chalk either encrusting other shells or unattached.

Great variety of zoarial and zooecial structures allow the recognition of six distinct orders of Bryozoa. Three orders are extinct and three have long geological histories and are still living.

3. Bryozoan Orders

One peculiar order of Bryozoa, the Ctenostomata, may be set aside from the rest. These forms have only chitinous skeletons which will not preserve fossil. They are known to have a long geological history because of their distinctive habit of boring into the shells of other organisms. Borings of ctenostome Bryozoa are known from the Ordovician onward. They occur throughout the geological column and at the present day, but they have never been an abundant element of bryozoan faunas.

The remaining orders, the members of which all secrete calcareous skeletons, comprise the Cryptostomata, the Trepostomata and the Cystoperata (all ranging from the Ordovician to the Permian), and the Cyclostomata (ranging from the Ordovician to the present day) and the Cheilostomata (ranging from the Lower Cretaceous to the present day).

A basic structural distinction is evident if the cheilostomes and other bryozoan orders just mentioned are compared. The cheilostomes have short, box-like zooecia with each orifice closed by an operculum whereas the other orders have open-ended tubular zooecia.

The essentially tubular form of the zooecia of most orders of Bryozoa is well displayed by the cyclostomes. By the development of large numbers of contiguous tubes substantial colonies of zoaria may be formed. Meandropora from the Coralline Crag of Suffolk is a well known example.

In the Cyclostomata the open-ended calcareous tubes have porous walls. The zooecial tubes may be partitioned by diaphragms, though these are often absent. The only specialized zooecia are those in which the embryos and larvae develop. The cyclostomes are abundant throughout the geological column but are particularly common in the Jurassic and Cretaceous.

Trepostomata secreted heavily calcified skeletons. The zooecial tubes have many partitions and several distinctive types of zooecia were developed. The zooecia were often massive, though many delicately branched forms occurred also. This order is sometimes termed the 'stony Bryozoa' and zoaria may be many centimetres across. The functions and structures of this exclusively Palaoezoic order, like those of the Cystoporata and Cryptostomata, are interpreted chiefly by comparison with living Cyclostomata.

Cryptostomata include probably the most familiar of Palaoezoic Bryozoa - the fenestellids. In the cryptostomes the zooecia are short, sharply bent tubes which, in the fenestellids, open on one side only of the branches forming the zoaria. The branches are joined by cross-bars giving the characteristic net-like appearance to the whole colony. The very short tubular zooecia of some cryptostomes have led some workers to propose this order of Palaeozoic Bryozoa as a precursor of the Cheilostomata which first appear in the Lower Cretaceous.

The Cheilostomata are by far the most numerous order of present day Bryozoa and have dominated bryozoan faunas since the Cenomanian. They swiftly evolved a great variety of form and structurally they include the most complex bryozoans.

Cheilostome zooecia are relatively short, being box-like with an operculum-covered orifice near the distal end of each zooecium. Depending on the way in which the tentacles are extruded through the orifice various structures are developed.

The most common of present day bryozoans around British coasts is *Flustra foliacea*. This species serves to demonstrate some of the basic features of cheilostome Bryozoa. The colony, or zoarium, is formed by repeated distal-lateral budding of zooecia which consist of basal and lateral calcareous walls the front being covered by a flexible chitinous front wall. The operculum is sited near the distal end of this front wall closing the orifice. In *Flustra* two sheets of zooecia are attached back-to-back forming a bilaminar colony of flat dividing branches. Muscles attach the tentacled zooid, inside each zooecium, to the flexible front wall. Contraction of these muscles reduces the internal space forcing the tentacles through the orifice. In the fossil state Bryozoa of this kind are open fronted since the chitinous front wall is not preservable. Cheilostome Bryozoa with a chitinous front wall are classed in the suborder *Anasca*. One specialised group of anascans is the *Cribrimorpha* in which marginal spines are arched over to fuse above the chitinous membrane.

Some cheilostomes, which are placed in the suborder *Asciphora*, have a heavily calcified rigid front wall. In these provision is made for extrusion of the zooid by a flexible chitinous compensation sac which opens through a pore just proximal to the operculum. Reduction of internal space caused by muscle contraction and filling of the sac with sea water forces the tentacles through the orifice. *Porina* is a characteristic ascophoran demonstrating the heavy calcification which may develop on the frontal area of this type of cheilostome.

There are thus two main structural types of cheilostome Bryozoa and these are related to the nature of the hydrostatic system controlling the extrusion of the zooid. The order is also distinguished from other Bryozoa by the occurrences of highly specialised zooecia (heterozooecia) which lack tentacled individuals. These heterozooecia include ovicells (calcified globular chambers which occur distally to some mature zooecia and

house the developing larvae), avicularia (modified zooecia with muscles only which activate a snapping chitinous mandible hinged on a median frontal cross-bar) and kenozooecia (sealed individuals which occur sporadically in the colony).

Since cheilostome Bryozoa form colonies by repeated budding from a first-formed zooecium (the ancestrula) it follows that analysis of the successive cycles of zooecia in a zoarium reveals astogenetic changes during ontogeny.

Structural patterns, modifications of zooecia and astogeny are thus important features to note in interpreting the nature and significance of the earliest cheilostome Bryozoa. These occur in rocks of Albian age in Britain and Texas. Records of Middle Jurassic cheilostome bryozoans are erroneous. The specimens on which such records were based have been shown to have come from late Upper Cretaceous horizons.

4. Origin and Evolution of the Cheilostomata

In Britain the earliest known cheilostome Bryozoa are of Albian age. Rhammatopora occurs in the lowest Middle Albian Gault Clay of Cambridgeshire and in the lower part of the Red Rock of Hunstanton, Norfolk (Thomas and Larwood 1960). The zooecia are pyriform with pronounced proximal caudae. The frontal aperture is simple with minute spines. Zooecia bud from one another distally and laterally to form widespread colonies encrusting shells of other organisms. The genus is very similar to the present-day Pyripora which may be found in Britain in Cenomanian horizons and throughout the Cretaceous and Caenozoic. Charixa (Lang 1915), a multiserial pyriform cheilostome, also occurs in the Gault Clay of Charmouth, Dorset.

In the U.S.A. Pyripora has been found encrusting the test of an echinoid from the Comanchean (Middle Albian) Stage of the Fort Worth Limestone (Thomas & Larwood 1956, 1960). Additionally a membranimorph cheilostome has been found in the De Queen Limestone (Albian) of Arkansas and Wilbertopora (a membranimorph with avicularia and ovicells) is also known from the Fort Worth Limestone (Cheetham, 1954).

Thus in two very widely separated areas simple encrusting pyriporimorph and membranimorph anascan cheilostomes are the earliest forms found and these are interpreted as radical forms from which varied cheilostomes quickly evolved in the Cenomanian.

The base of the Cenomanian over much of the world was marked by an extensive marine transgression and the accumulation, in shallow shelf conditions, of sandy limestones. In this newly

available and congenial environment cheilostomes swiftly diversified. Forms such as Membranipora became common, and, by the overarching and fusion of their marginal spines, swiftly gave rise to cribrimorph Bryozoa (Larwood 1962). Thus three groups, the pyriporimorphs, the membranimorphs and the cribrimorphs evolved from the Cenomanian onward as distinct stocks. The pyriform types underwent little evolutionary change but the other two stocks became very varied and gave rise, in the Turonian, to the ascophoran cheilostomes which became more numerous, but not dominant, during the Tertiary.

It seems evident that the new, varied and vigorous cheilostome fauna competed successfully with the established cyclostome Bryozoa during the early Upper Cretaceous and by mid-Senonian times the cheilostomes became the dominant order. From the Turonian ascophorans swelled the ranks of the cheilostomes and, together with non-cribrimorph anascans, dominate the cheilostome fauna of the Caenozoic and the present day.

The gap between the three Palaeozoic orders of Bryozoa and the Cretaceous and later cheilostomes is bridged, stratigraphically, by the cyclostomes. Structurally these seem the least likely precursors of the Cheilostomata. The tubular form and general absence of specialised zooecia serves rather to separate than to connect the cyclostomes with the cheilostomes. Ingoring the stratigraphical gap, the short tubular zooecia of the cryptostomes have been mentioned as possibly indicating affinity between that order and the short box-like zooecia of the cheilostomes. Such a tenuous affinity is possibly strengthened by the apparently similar modes of skeleton secretion in the two orders. Tavener-Smith (1969) has recently demonstrated that it is very probable that fenestellid cryptostomes secreted large parts of their zoarial skeleton from an external mantle-like layer of soft tissues - an overfold extension of the ectoderm. The same arrangement appears to occur in cheilostomes which have much secondary calcification of the frontal structures.

If the cheilostomes are to be derived from the cryptostomes then it is reasonable to suppose that some trace of connecting forms should be preserved in Triassic or Jurassic and earlier Lower Cretaceous strata. Such forms have not yet been recognised. It may be that some cyclostomes have been misinterpreted structurally and that the Cyclostomata is an artificial order concealing homeomorphic forms of different affinities. Progress is likely to be made in reinterpretation of the cyclostome Bryozoa which are undergoing, for the first time,

a complete systematic revision based both on observation of external form and on orientated thin sections.

One order, the Ctenostomata, has persisted from Ordovician times. The Cheilostomata may well be derived from these chitinous forms by the calcification of the zooecial wall during the Lower Cretaceous. Such a ctenostomatous origin is increasingly favoured as a source of early cheilostomes. Their sudden appearance near the top of the Lower Cretaceous and rapid diversification and evolution thereafter on a worldwide scale is evident. Such a pattern makes these Bryozoa valuable fossils for long and short range stratigraphical correlation and, by analysis of assemblage components, useful indicators of palaeo-environments.

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GEOLOGICAL SOCIETY OF NORFOLK

BULLETIN

No. 18 Editor: C.E. Ranson
November 1969

Contents

NOTICES AND NOTES

<u>Forthcoming Meetings</u> (directions to venues at U.E.A. can be obtained from the Porters at the entrance to either the University Plain or University Village sites, as appropriate. Buses stop at Earlham Park Gates for the University Village and at University Plain for the University Plain itself.)

<u>Thursday, 11th December</u>: Talk, "Margins of modern ice sheets and their relevance to the glacial geology of Norfolk" by Dr. G.S. Boulton, University of East Anglia. 7.30 p.m., at Norwich Castle Museum. (PLEASE NOTICE CHANGE OF DATE, see below for details of meeting on November 27.)

<u>Monday, 29th December</u>: A.G.M. in Lecture Theatre 2, Block C, University Village, University of East Anglia, Wilberforce Road, at <u>7.00 p.m.</u> For Agenda see last page of this Bulletin.

To be followed by a programme of films lasting approximately 80 minutes, and consisting of the following titles:

"The Changing Earth"

"The Search for Oil"

"The Underwater Search"

Thursday, 15th January, 1970: Presidential Address, "The Origin of the North Sea" by Prof. B.M. Funnell, University of East Anglia, 7.30 p.m. Lecture Theatre 3, Lecture Theatre Block, University Plain, University of East Anglia.

Thursday, 19th February, 1970: Members evening, "Show it Yourself", an opportunity to bring along and present your favourite lantern slides on geological and related matters. 7.30 p.m., Norwich Castle Museum.

Thursday, 12th March, 1970: Talk, "Soil surveying in Norfolk and Suffolk" by W.M. Corbett, Soil Survey of England and Wales. 7.30 p.m. Norwich Castle Museum.

Other meetings

Thursday, 27th November, 1969: U.E.A. Environmental Society - Lecture, "Oceanographic problems in the North Sea" by Dr. T.G. Gaskell, Scientific Adviser to Information Department, British Petroluem. 8.00 p.m., Arts Block Lecture Theatre 0.24, University Plain, University of East Anglia.

Monday, 19th January, 1970: Geographical Association - Lecture, "Coral Islands of the Indian Ocean" by D.R. Stoddart, University of Cambridge. 7.30 p.m. Music Room, Assembly House, Norwich.

Thursday, 29th January, 1970: U.E.A. Environmental Society - Lecture, "Ridges, Plates and Trenches" by Prof. Sir Edward Bullard, University of Cambridge. 8.00 p.m., Arts Block Lecture Theatre 0.24, University Plain, University of East Anglia.

Saturday 21st March, 1970: Norfolk Research Committee - Presidential Address "Research into Norfolk - problems and prospects" by Prof. B.M. Funnell, University of East Anglia. 2.30 p.m., Norwich Castle Museum.

Notes

Copies of the Constitution of the Geological Society of Norfolk (adopted October 2, 1969) will in future be sent to all new members on joining. A copy for existing members is included with this Bulletin.

The List of Members which forms part of this Bulletin is as correct and up-to-date as we can make it. Please make any corrections or subsequent amendments known to the Hon. Sec. (Mr. Brian McWilliams, Castle Museum, NORWICH NOR 65B) as soon as possible.

It is hoped that a reprint (with amendments) of "The Geology of Norfolk" edited by G.P. Larwood and B.M. Funnell, and originally published jointly by the Norfolk and Norwich

Naturalists' Society and the Paramoudra Club in 1961, will be available and on sale by March 1970. Members will be notified of details with the announcement of the Spring and Summer Field Programme.

Contributions for Bulletin No. 19, which will very probably be issued in off-set litho format in the Autumn of 1970, should be submitted to the Editor (Mr. C.E. Ranson, The Nature Conservancy, 19 East Hill, Colchester) as far in advance as possible. Your contributions are invited.

Back numbers of the Bulletin where still available, may be obtained from the Hon. Secretary (see above) at 3s.6d. per copy, (4s. inclusive of postage).

Members are reminded that subscriptions for 1969-70 are now due and should be remitted to the Hon. Treasurer (Mrs. G. Cheeseman, 22 Firs Road, Hellesdon, NORWICH NOR 39M) as soon as possible. Members using bankers' orders should amend the date of payment forward to October 1st (no longer January 1st) to bring them into line with the new constitution.

OBSERVATIONS ON IRON MINERAL GEODES IN NORFOLK

BY

A.K. FOWLER

C.B. Rose (1836) observed 'geodes, containing sand, small hollow cylinders, and flat fragments of ironstone .... very abundant' at Shouldham Warren and 'most other localities' on the Greensand outcrop in West Norfolk. They are visible today in a large, shallow quarry 1 mile south of Sandringham Park, occurring in a 7 foot stratum overlying the Carstone. This stratum has yielded geodes of various ferric iron compounds, showing moulds of bivalves (Trigonia sp.) and of wood.

I have written this short account outlining the difficulties in explaining the origin of geodes since they are abundant in the Crags and in the glaciofluvial and glacial deposits in Norfolk, and frequently catch the eye of anyone looking at these deposits. The literature on this subject is far from helpful: the general view among geologists is that geodes result from concentrations of iron-bearing solutions caused by local lithological variations within porous strata, or by the conversion of iron pyrites. However, neither of these suggestions appears in print.

After studying these geodes I have found these explanations to be inconsistent with certain features. Many specimens are not relatable to lithological variations in the surrounding strata likely to cause impediment to iron-bearing solutions. Some contain loose deposits within the central cavity which are different from the deposits surrounding them. The central cavity is itself problematical when the conversion of iron pyrites is considered as a mode of formation for the geodes. The oxidation and hydration of iron pyrites to form colloidal iron hydroxide elsewhere produces ehrenwerthite, which is a solid pseudomorph after iron pyrites - a process which is unlikely to produce a cavity in consolidated deposits.

The walls of the geodes vary greatly in thickness, and there is no clear relationship between their thickness and the diameter of the cavity. The cavity is often irregular in shape. The walls may be homogeneous, but often have a layered structure, with pale, soft forms of limonite ($2Fe_2O_3.3H_3O$) grading into or adjacent to one of its several harder and darker varieties. Some specimens show as many as five distinct layers in the wall, often reflecting a change in form from the shape of the cavity to the shape of the outer wall. One specimen in the author's possession has multiple concentric cavities. Of those so far collected, only specimens from the Greensand distinctly show material from the surrounding stratum incorporated in the wall material. While

most of the geodes are surrounded by a zone stained with limonite, some, as in the Norwich Brickearth, have no stain surrounding them, and have a polished and striated outer surface. The contents of the cavities vary from loose, limonitic clay or sand to an unidentified grey, acicular material, rarely filling the cavity. In many cases the cavity is devoid of loose material.

In view of the foreign material found in some specimens, the difficulty of relating any specimens to local zones of iron enrichment, the signs of erosion found on the specimens from the Norwich Brickearth, and the similarity of grade of the geodes to that of pebbles in the same stratum, it seems likely that specimens showing these features have been transported from their place of formation. The most likely source of geodes frequently found within glaciofluvial and glacial deposits is the Greensand, or perhaps, the Crags.

The mode of formation of these geodes remains in doubt. The accepted theories on the formation of ironstones in the Mesozoic as outlined by the Geological Survey (Taylor 1949, Whitehead _et al_. 1952) do not mention cavities surrounded by iron minerals and occurring within consolidated strata. The work of Moore and Maynard (1929) concerning bacterial/electrolytic precipitation of iron colloids in marine environments may be relevant to this problem. Further work is needed on the geodes of the Greensand, and on the physical and chemical nature of their walls.

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Editors note: Since this paper was submitted the following relevant article has appeared in the journal, "Palaeogeography, Palaeoclimatology and Palaeoecology":

van der Burg, W.J. 1969. The formation of rattle stones and the climatological factors which limited their distribution in the Dutch Pleistocene, 1. The formation of rattle stones. _Palaeogeog. Palaeoclim. Palaeoeecol_., _6_ (2), 105-124.

NOTES CONCERNING SOME RHYNCHONELLID AND TEREBRATULID BRACHIOPODS OF THE UPPER CHALK ZONE OF BELEMNITELLA MUCRONATA IN NORFOLK

by Michael Leeder

(Formerly Department of Geology, University of Durham, now Department of Geology, University of Reading)

The zone of _Belemnitella mucronata_ in Norfolk contains an abundant brachiopod fauna. By using the stratigraphical subdivisons proposed by Peake and Hancock (1961), some suggestions can now be made concerning their vertical distribution. Several hundred individuals have been collected and their external morphology studied. Until a considerable amount of work is done on the internal morphology of these brachiopods no satisfactory specific definitions can be upheld. However, this account, when used in conjunction with the results of studies on belemnites and echinoids, may prove useful to those whose work demands an accurate knowledge of the stratigraphy of the Upper Campanian. In particular, it should help in determining the horizon of temporary exposures.

Rhynchonellids

(i) Systematics

Pettit (1950-65) divided the genus _Cretirhynchia_ into three broad series based primarily on the nature of the costae: namely the _C. plicatilis_, _C. exculpta_ and _C. limbata_ series (Table I). _Cretirhynchia_ itself is a common genus throughout the Chalk and in the Norwich Chalk is the only rhynchonellid so far recorded.

Pettit remarks that the last mentioned series differs in internal structure from the former two and that he had considered splitting them off to form a distinct genus. The most remarkable difference is the posterior smoothness of the shell in the '_limbata_ series'. Thus _C. lentiformis_ Woodward and _C. arcuata_ Pettit are both smooth almost to the commissure.

An examination of _C. norvicensis_ Petit and _C. woodwardi_ Davidson, of the '_plicatilis_' and '_exculpta_ series' respectively has established that:- (a) many individuals of _C. norvicensis_ exhibit both incipient splitting and reduction of costae around the anterior and antero-lateral commissure, (b) _C. woodwardi_ can be distinguished from _C. norvicensis_ by its broad, arcuate plication of the anterior commissure and its much larger width/length ratio. The former is much rarer and seldom shows reduction of costae on anything like the scale exhibited by _C. norvicensis_.

Table 1: The 'series concept' amongst Upper Cretaceous specimens of the genus Cretirhynchia (abstracted from Pettit 1950-65)

SERIES	PRINCIPAL DIAGNOSTIC FEATURES OF THE SERIES	SPECIES DEALT WITH HEREIN
Cretirhynchia plicatilis series	Reduction of costae in number along anterior commissure	C. norvicensis
Cretirhynchia exculpta series	Incipient splitting of costae along anterior commissure	C. woodwardi
Cretirhynchia limbata series	Posterior part of valves smooth. A few low costae near anterior commissure	C. lentiformis C. arcuata

It is clear from (a) that Pettit's 'series concept' as a classificatory grade (albeit informal) does not stand up to rigorous examination and should be discontinued.

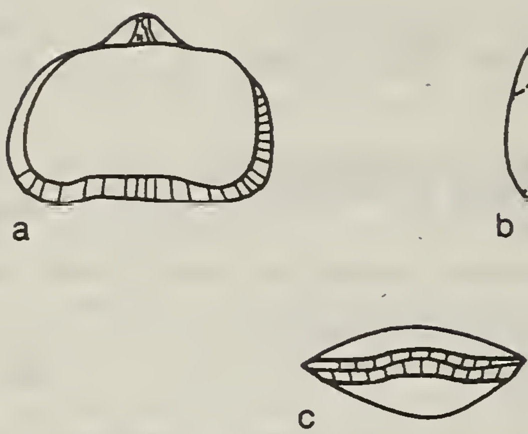
Future work on the vertical distribution and evolution of the various species of Cretirhynchia will depend critically upon the use of serial sectioning techniques.

(ii) Stratigraphical distribution (Fig. 2)

C. norvicensis Pettit ranges from the base of the Weybourne Chalk to well into the Paramoudra Chalk.

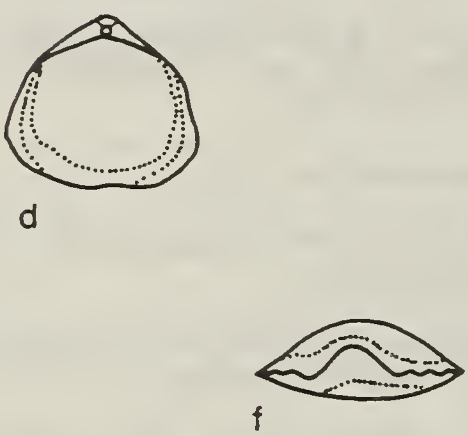
C. woodwardi Davidson ranges from about 20' below the Catton Sponge Bed to the base of the Beeston Chalk.

C. lentiformis Woodward ranges from about the top of the Basal Mucronata Chalk to the top of the Beeston Chalk where it becomes scarce. I propose to name informally two forms of this species based on clear and objective differences in external morphology. They are not to be regarded as Linnean species but as incompletely known variants from a published description (Pettit 1950, pp.26-27, Pl.II, Figs.1a-c) which are useful stratigraphically. There will be no need for such perversions of nomenclature once Pettit's monograph has been revised.



a. dorsal view
b. lateral view
c. anterior view

Fig.1a–c *Cretirhynchia lentiformis* α
Earlham, temporary exposure – Upper Eaton Chalk
x3



d. dorsal view
e. lateral view
f. anterior view

Fig.1d–f *Cretirhynchia lentiformis* β
Caistor St. Edmunds Quarry – lower Beeston Chalk
x3

Cretirhynchia lentiformis α (Fig. 1a-c)

Mature shell shows a broad well-developed plicate commissure with up to 9 small costae developed close to the anterior commissure. The linguiform extension is broadly trapezoidal. This form may be up to 13 mm wide, 12 mm long and 7 mm high and ranges from the top of the Basal Mucronata Chalk to the middle of the Weybourne Chalk.

Cretirhynchia lentiformis β (Fig. 1d-f)

Generally narrower individuals with a lenticular to pear shape in dorsal view. Commissure gently to sharply plicate with up to 4 broad costae developed at the very margin of the anterior commissure. The linguiform extension often tends to a V-shape and is much narrower than in the form α. It ranges from the middle of the Weybourne Chalk to the Paramoudra Chalk, where it becomes rare.

It is often dificult to distinguish between young individuals of C. arcuata and mature C. lentiformis in the Weybourne and Beeston Chalks.

C. arcuata Pettit ranges from the Upper Weybourne Chalk to the top of the zone and rapidly becomes the most abundant species of brachiopod in the Beeston Chalk at Caistor St. Edmunds and Frettenham pits. Usually much larger than Pettit's optimum measurements (up to 22 mm wide, 19 mm long and 13 mm high).

Terebratulids

(i) Systematics

On the basis of internal and external morphology Sahni (1929) described the genera Magnithyris, Piarothyris, Ornithyris, Ellipsothyris, Carneithyris and Neoliothyrina from the Belemnitella mucronata zone in Britain, with nearly all his material coming from Norfolk. He founded a total of 18 species altogether. Muir-Wood (1953) considers the genera Magnithyris, Piarothyris, Ornithyris and Ellipsothyris as 'variants of Carneithyris and not distinct genera'.

(ii) Stratigraphical distribution

Sahni (op. cit) emphasised the considerable homeomorphy shown by the Carneithyrids (sensu Muir-Wood) and because of this and the confused state of the systematics of this group at the present time, it seems unwise to consider precise ranges although abundant material is available for study.

However, one fact brought out during collecting is the apparent absence of Carneithyrids in the Basal Mucronata and Eaton Chalks. They are found only rarely below the Upper Weybourne Chalk, but at and above this horizon they become extremely abundant. All of Sahni's material came from pits now thought to be in the Upper Weybourne, Beeston and Paramoudra Chalks.

<u>Figure 2</u>: Stratigraphical distribution of some rhynchonellid and terebratulid brachiopods in the zone of <u>Belemnitella mucronata</u> (U. Campanian) in Norfolk. Stratigraphy mainly after Peake and Hancock (1961).

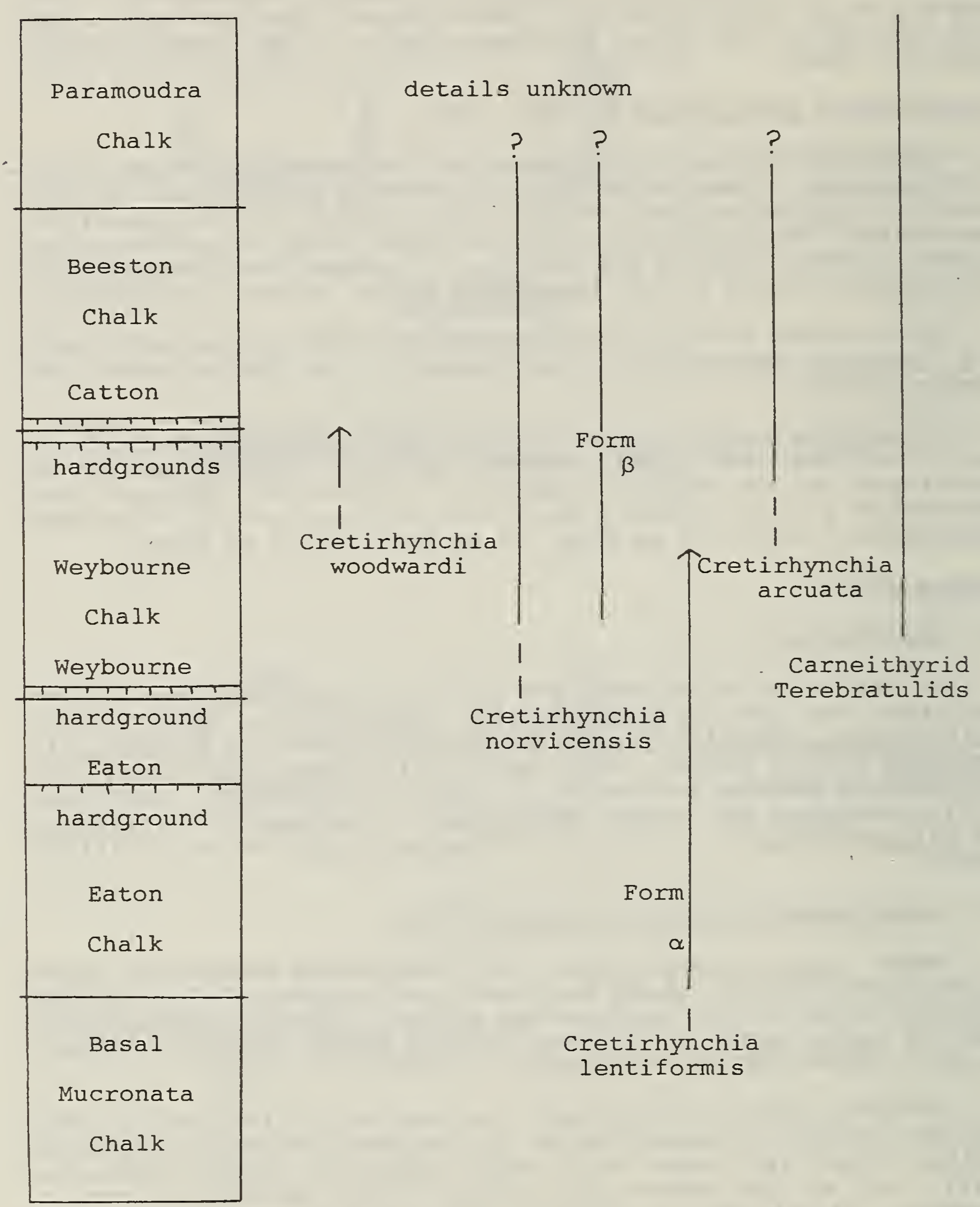


Table 2: Exposures at which brachiopods may be collected inland in the Upper Campanian (Horizons mainly after Peake & Hancock 1961)

Exposure	Horizon	Occurrence and frequency of species	
Frettenham Quarry	?U. Beeston Chalk	Carneithyrids	c
		Cretirhynchia arcuata	c
		Cretirhynchia norvicensis	c
		Cretirhynchia lentiformis β	r
Caistor St. Edmunds Quarry	L. Beeston Chalk	Carneithyrids	c
		Cretirhynchia arcuata	c
		Cretirhynchia norvicensis	c
		Cretirhynchia lentiformis β	c
Catton Quarry	Catton Hardground U. Weybourne Chalk	Carneithyrids	c
		Cretirhynchia arcuata	c
		Cretirhynchia norvicensis	c
		Cretirhynchia woodwardi	c
		Cretirhynchia lentiformis β	c
Keswick Quarry	M. Weybourne Chalk	Carneithyrids	r
		Cretirhynchia norvicensis	r
		Cretirhynchia lentiformis β	c
		Cretirhynchia lentiformis α	c
Eaton Quarry and temporary exposures at the U.E.A.	M. - U. Eaton Chalk	*Cretirhynchia lentiformis*	c
		Cretirhynchia aff. *norvicensis*	r
		Cretirhynchia sp.	r
		Carneithyrids	vr
Cley Pit	L. Eaton Chalk	*Cretirhynchia lentiformis* α	fc
Drayton Pit	L. Eaton Chalk	*Cretirhynchia lentiformis* α	c

Neoliothyrina obesa Sahni, a very striking terebratulid, sets in at the base of the Weybourne Chalk (where it is uncommon) and ranges up through the zone and occurs in the Lower Maestrichtian at Trimingham. It is much rarer than the Carneithyrids.

Conclusions

It is apparent that much systematic work is needed before U. Campanian brachiopod faunas can yield evidence concerning their evolution. Bearing this in mind, any detailed study concerning the palaeoautecology of brachiopods in the Upper Campanian (and indeed, probably the whole of the Chalk) would seem to be premature.

Acknowledgements

I wish to thank Dr. J.M. Hancock, Prof. D.V. Ager and Mr. N.B. Peake for reading and commenting on earlier versions of this study. Mr. Peake has given help and encouragement over a period of years while Mr. A. Drane has also collected a large amount of material. To some extent the opinions expressed above belong jointly to Mr. Drane and myself.

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Sahni, M.R. 1929. A Monograph of the Terebratulidiae of the British Chalk. *Palaeontogr. Soc. (Monogr.)*.

A PRELIMINARY ACCOUNT OF RESEARCH BOREHOLES AT STRADBROKE AND HOXNE, SUFFOLK

by. A.R. Lord,

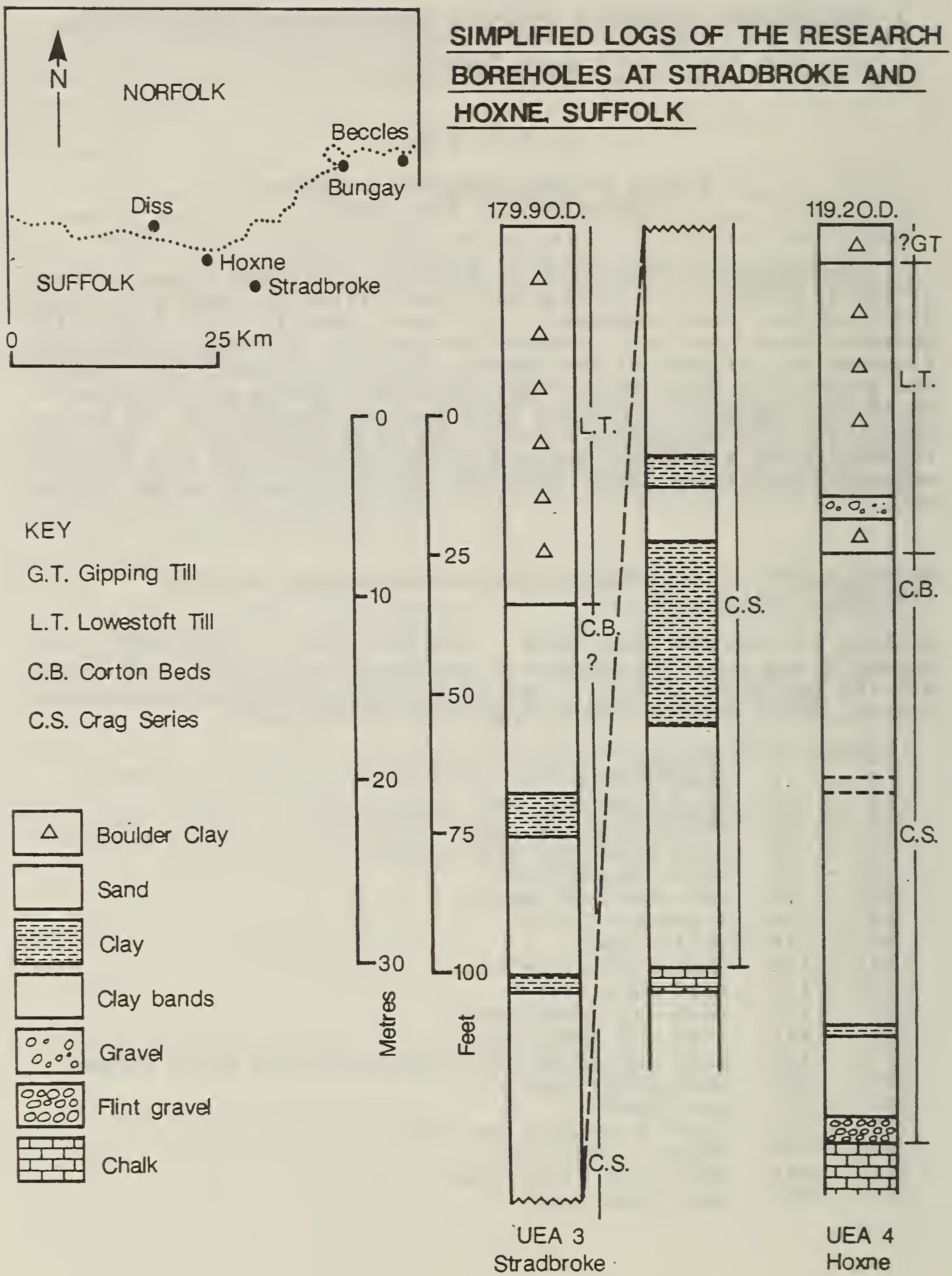
School of Environmental Sciences,
University of East Anglia

The previous issue of this Bulletin contained a description of two boreholes, at Beccles and Great Yarmouth, which had been drilled for the University of East Anglia and Cambridge University as part of a research project on the Lower Pleistocene financed by the Natural Environment Research Council (Lord 1969). The present account describes the second phase of drilling in which two research boreholes were made at Stradbroke and Hoxne. Detailed investigations into the distribution of pollen, foraminifera and other marine microfossils, and the palaeomagnetic history of these boreholes are at present being carried out.

Borehole UEA 3. Stradbroke Priory, Stradbroke, Suffolk
(TM 2326 7382)

Drilled in June and July, 1969. Surface level + 179.9′ O.D. The borehole was made six yards to the north of the site of a well drilled for water in 1933. The succession proved by the original boring, which was never published, was as follows:

0′ - 2′	soil
2′ - 12′	yellow clay
12′ - 13′	hard blue clay and stones
13′ - 15′	boulder, stone bed
15′ - 50′	hard blue clay and stones
50′ - 59′	brown silty clay
59′ - 64′	red sand and gravel
64′ - 91′	light grey sand
91′ - 94′	yellow sand
94′ - 123′	dark blue silty clay
123′ - 131′	hard dark sand
131′ - 151′	hard dry green sand
151′ - 161′	hard dry green sand
161′ - 200′	hard dry green sand with shell and small stones
200′ - 212′	dark silty clay
212′ - 219′	grey sand
219′ - 255′	light blue clay and silt
255′ - 265′	ditto - grey silt
265′ - 281′	dark blue silty clay
281′ - 285′	dark blue sand


SIMPLIFIED LOGS OF THE RESEARCH BOREHOLES AT STRADBROKE AND HOXNE, SUFFOLK
N
NORFOLK
Beccles
Bungay
Diss
Hoxne
Stradbroke
SUFFOLK
0
25 Km
KEY
G.T. Gipping Till
L.T. Lowestoft Till
C.B. Corton Beds
C.S. Crag Series
Boulder Clay
Sand
Clay
Clay bands
Gravel
Flint gravel
Chalk
0
10
20
30
Metres
0
25
50
75
100
Feet
179.9 O.D.
L.T.
C.B.
?
C.S.
119.2 O.D.
?GT
L.T.
C.B.
C.S.
UEA 3
Stradbroke
UEA 4
Hoxne

285′ - 308′	light grey sand
308′ - 310′	dark grey clay
310′ - 325′	dirty chalk
325′	white chalk

chalk proved to a total depth of 386′ below the surface.
(A 5" boring made by H. Warner & Son, Ipswich. Water level - 94′ after pumping)

The site was of special interest because of the very thick Crag sequence (apparently from about 70′ to 310′), for the thick clay layers suitable for pollen analysis and palaeomagnetic studies, and for the general geographic location which is over a deep hollow in the Chalk basement. It was thought that the borehole might provide information about the origin of the Crag basin and the time of its formation.

A comparison of the sequence proved by borehole UEA 3 (see figure) with that in the old log shows that the latter is somewhat generalised and correlation between the two possible only in the broadest way. In particular there is some discrepancy over the occurrence of the thick clay and silt bands in the two successions. The boulder clay (till) at the top of the borehole was a hard dark blue or grey clay with a high chalk pebble content thought to be the Lowestoft Till. Beneath the till were coarse red sands and gravels wich extended to a depth of 81′ where fine grey sands were encountered. Part of these red sands contain chalk and flint pebbles and may well belong to the Corton Beds. The grey sands are Crag with the iron salts in a reduced state. The figure shows that four substantial argillaceous beds and a number of thin bands were found, but that the major part of the sequence consisted of green or grey shelly sands.

A total of twenty-two cores and more than one hundred and eighty disturbed samples were collected from this borehole.

Borehole UEA 4. Hoxne Rectory, Suffolk (TM 1810 7757)

Drilled in July, 1969. Surface level + 119.2′ O.D.

The borehole was made in the vicinity of the site of a previous well drilled behind Hoxne rectory in 1877. The precise location of the previous well is unknown. The old log (Whitaker 1906, p.71) gave the following successions:

0′ - 50′	old well (39′ of clay over sand to a depth of 45′)
50′ - 74′	(boulder) clay and large flints
75′ - 91′	loose running sand and crag (red)
91′ - 92′	light-blue clay
92′ - 152′	loose running sand and crag (many specimens of *Purpura lapillus*)
152′ - 161.5′	light-coloured clay

163′	chalk
	(chalk proved to a total depth of 203′ below the surface)

This locality is situated close to the western margin of the Crag basin and on the western side of the Crag-filled trough in the Chalk, the deeper part of which was penetrated by the Stradbroke Borehole (UEA 3). The villages of Hoxne and Stradbroke stand at the north-eastern end of the trough where it joins the main Crag basin, from these sites the trough runs in a south-westerly direction to Stowmarket. This borehole was drilled to provide information about the littoral facies of the Crag basin.

The boulder clay rested on yellow and red sands, and gravels with chalk fragments, which persisted for 20.5′ to a depth of 79′ where comminuted shell was detected in the sands, at least part of these sands probably below to the Corton Beds. The yellow and red sands with shell continued to a dpeth of 94.5′ where the colour of the sediment changed from red to grey. The sands from 92′ to 94.5′ resembled Red Crag. Green-grey shelly sands with a number of thin clay bands continued to a depth of 161.5′ where a bed of coarse flint gravel was found. The gravel was 5.5′ thick and composed of rounded flints, most of which were 3-4" long and possessed a green or grey coating. The Chalk was reached at a depth of 167.5′, beneath the thick flint gravel bed. The general sequence of sediments recorded in the old log was found to be correct but, as was to be expected, there were many differences in detail. In particular the 9.5′ bed of clay recorded from 152′ clearly represents a series of clays and sands rather than a discrete clay unit. As mentioned in the old log, Purpura lapillus was very common in the Crag sands. The sequence proved in this borehole was little different from that found in deeper parts of the Crag basin, with the notable exception of the very substantial basal flint bed.

Acknowledgements

The generous co-operation of Mr. and Mrs. J.C. Claydon (Stradbroke Prior) and the Venerable and Mrs. G. Scott (Hoxne Rectory) is gratefully acknowledged.

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Nos. 11-18 (REPRINT)

INTERGLACIAL BEDS AT BEETLEY, NORFOLK

By

R. Markham (Ipswich Museum)

The 1964 discovery of richly fossiliferous 'interglacial' beds at Roosting Hills, Beetley, Norfolk, pit of the St. Ives Sand and Gravel Co. is of importance in deciphering the Pleistocene history of Central Norfolk.

The folloiwng sequence was exposed in part of the pit:-

H -	Greenish (greyish when dry) stony silt	c. 1.83m
G -	Pale coloured sand	.91-1.22m
F -	Black (grey when dry) silty sand	.20- .23m
E -	Pale coloured, sub-angular sand and gravel	.25m
D -	Black sand and gravel	.18- .20m
C -	Black (light grey when dry) organic silt	.64m
B -	Grey-green (greyish when dry) silt sand, with stones and chalk pebbles	.71m
A -	Coarse, yellow-orange sand and gravel	c. 4.52m (max. seen)

In the northern part of the pit, the organic beds are absent, bed H apparently resting directly on A.

Typical Cannonshot Gravel is exposed in pits higher up the southern sides of the valley (a tributary of the River Wensum) in which the Beetley Beds occur.

Notes on Beds

B - fairly compact silty sand; large stones at base. Contains small angular and subangular flints, abundant small fragments of fairly hard chalk, fragments of wood (often slightly carbonised) and small pieces of planty material.

C - organic silt, containing abundant small pieces of plant material and many fragments of non-marine molluscs. Pieces of conifer wood, often several feet in length,are common near the base; a fir-cone was found in situ in this bed. Fragments of plant stem (some flattened), seeds, and pieces of moss are fairly common. There are many fragments of univalve and bivalve molluscs, but only a few have been found complete, mainly Ancylus and Planorbis spp.; operculae of Bythinia are very common. Other fossils present include fragments of beetle elytrae and a few fish scales.

E - medium gravel. Wood fragments, a bone (part in bed E and part in bed F) and a bovid tooth (apparently from this horizon) were found during a Paramoudra Club excavation.

F - bones fairly common during Paramoudra Club excavation; shattered tusk of elephant, and rhinoceros tooth, found in situ. Small fragments of planty material are common, but do not approach the abundance as in the far less sandy bed C.

G - bones fairly common, including fragmentary long bones and (?) rib. The bones from this horizon are spongy in texture and difficult to extract, quite unlike the condition of those in bed F, which are hard.

H - stony, silty sand, hard; stones generally fairly angular. A few small pieces of vegetable material. An astragalus (not in situ) may have come from this bed.

Notes on fossils

Several mammalian species have been found

Hippopotamus amphibius Linne	Hippopotamus
Palaeoloxodon antiquus (Falconer & Cautley)	Straight-tusked elephant
'Rhinoceros' sp.	Rhinoceros
Cervus elaphus Linne	Red Deer
Megaceros giganteus (Blumenbach)	Giant Deer
Bovid, probably Bison sp.	Bison

Remains of hippopotamus are common (mandible, radius-ulna, scapula, tibia, etc.), those of elephant (upper molar, etc.) and bovid (fragments of horn-core, radius, teeth) less so, while rhinoceros (upper molar), red deer (frontal and antler base) and giant deer (base of shed antler) are represented by only a few specimens. The giant deer antler is more heavily mineralised than the other fossils. Most of the bones are now in the Norwich Castle Museum. It is suggested that the majority of these bones (most of which were found loose), because of their colour and hardness, have in fact been derived from horizon F (where similar remains are found in place).

The many loose cones found on the spoil heaps seem most likely to have come from stratum C, where one cone was in place, and in which conifer wood is common.

Some loose shelly blocks yielded bivalves, particularly Sphaerium.

Periglacial Action

Cryoturbation phenomena are seen below bed H, and a large frost wedge was found cutting down through bed F.

Note on Sequence and Dating

Bed C: the quantity of well-preserved fir-cones and conifer wood shows the dominant trees of the neighbourhood.

Assuming the bulk of the recorded mammalian fauna to have come from horizon F, a temperate climate is indicated at this stage.

Colder conditions after the warm phase are shown by the structures mentioned under 'Periglacial Action'.

The mammalian fauna is close to that recorded elsewhere from zone F of the Ipswichian interglacial.

(Adapted from an account by the same author in the Bulletin of the Ipswich Geological Group, No.3, August 1967, pp.4-5).

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Agenda

of Annual General Meeting to be held at 7.00 p.m., Monday 29th December 1969

1. Minutes of the A.G.M. held 21st Dec. 1968
2. Minutes of the E.G.M. held 2nd Oct. 1969
3. Matters arising
4. Reports of Officers for 1969
    - (a) Secretary
    - (b) Treasurer
    - (c) Editor
    - (d) Fieldwork Secretary
5. Election of Officers and committee for 1970

    President
    General Secretary
    Treasurer
    Editor
    Fieldwork Secretary
    Three ordinary committee members
6. Programme for 1970
7. A.O.B.

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The Geological Society of Norfolk exists to promote the study and knowledge of geology, particularly in East Anglia, and holds monthly meetings throughout the year. Copies of this Bulletin may be obtained from: The Secretary, Geological Society of Norfolk, Castle Museum, Norwich NR1 3JU.

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The illustration on the front cover is of early members of the Paramoudra Club at the City of Norwich School, Norwich, July 1951.

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